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AUTOMATION OF AN RCS MEASUREMENT SYSTEM

AND ITS APPLICATION TO INVESTIGATE

THE ELECTROMAGNETIC SCATTERING FROM

SCALE MODEL AIRCRAFT CANOPIES

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THESIS

Presented to the Faculty of the School of Engineering
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Preface

The purpose of this thesis was twofold. The first objective was to complete the development of the Air Force Institute of Technology (AFIT) Far-Field Radar Range with an automated and fully calibrated measurement process. The second objective was to use the range to investigate the scattering of metallic versus transparent canopies on the total Radar Cross Section (RCS) of fighter aircraft.

The first task was successfully completed, as the user can obtain calibrated and accurate RCS measurements from his or her seat in front of the Hewlett Packard computer and a copy of the AFIT RCS Measurement Software (ARMS) code, which is conveniently consolidated on one floppy disk. Investigative measurements were then taken of canopy models at the AFIT range and a similar, but more established facility at the Wright Research and Development Center. The results of the measurements simply quantify the relative level of the scattering from the cockpit/canopy area with respect to the total aircraft.

I owe many thanks to select people in completing this study. I could not have even begun this endeavor without the guidance and experience of my advisor, Capt Phil Joseph. His patience and skill in lessening the intimidation and frustration inherent in any topic dealing with electromagnetic scattering is noteworthy. I am grateful to Capt Cass Hatcher and his crew at the Air Force Orientation

Center, Defense Electronic Supply Center (DESC) for supplying me with crucial information and material for the low RCS test body. Thanks and much appreciation are also due to Dave Driscoll and Jack Tiffany of the AFIT Fabrication Shop for their design expertise and model-making prowess demonstrated in building the various models. Finally, I would like to recognize Butch Porter and his co-workers at the Barn for their flexibility and willingness to measure my targets. Most importantly, however, I thank my wife, Kathy, for her support, patience, and understanding throughout our entire AFIT experience.

Scott A. Owers

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Abstract

The purpose of this study was twofold. The first objective was to complete the development of AFIT's Far-Field Radar Range with a fully automated measurement process. The second objective was to use the facility to investigate the scattering of metallic versus transparent aircraft canopies relative to the scattering of the total aircraft. The approach for the investigation was: first, to measure scale model aircraft to determine the effect of the RCS of the canopy/cockpit area on the RCS of the total aircraft, and second, to design and measure a test body which would isolate the canopy/cockpit area from the rest of the aircraft.

The result of the work on the first task is a software package called AFIT RCS Measurement Software (ARMS). The successful performance of the far-field range was validated by very favorable comparisons with the Wright Research and Development Center's anechoic chamber. The scale model measurements suggest at most a 5 dB difference between the scattering from the two extreme cases. The test body, however, clearly demonstrated differences up to 20 dB at certain frequencies.

This study documents the upper and lower bounds of the subject measurements in an indoor measurement range. The Air Force has expressed interest in steering the investigation to examine materials and/or canopy construction.

AUTOMATION OF AN RCS MEASUREMENT SYSTEM AND ITS APPLICATION TO INVESTIGATE THE ELECTROMAGNETIC SCATTERING FROM SCALE MODEL AIRCRAFT CANOPIES

Introduction

The Radar Cross Section (RCS) of a target has received much attention in recent years, fueled in part by the advent of stealth technology. RCS is an important parameter which describes the amount of radar energy that a target scatters back to a radar receiver. Knowledge of what causes the RCS of a target is an invaluable tool for the designer of military vehicles. Determining the RCS of even simple objects however, is a complex matter. In fact, the RCS of certain 'simple' geometries cannot be calculated by current methods. The military significance of the RCS teamed with the limitations of theory in calculating it places a great deal of importance on the measurement of a target's radar cross section. A good measurement system will not only find the total RCS of a target, but will also identify the major contributors.

To make an RCS measurement, ideally, the target must be illuminated by a plane wave. A plane wave can be approximated by placing the target at a large distance from the source, so that the spherical wavefronts transmitted by the source are approximately planar by the time they reach the target. A measurement range that approximates a plane wave in this manner is known as a far-field, or spherical range. A rule-of-thumb for determining the minimum range separation, R, from source to target in a far-field range is given by

$$R \geq 5D^2/\lambda$$

where D is the crossrange extent of the target and λ is the operating wavelength of the radar. For example, if a target is three meters wide and is to be measured at 10 GHz, the required range separation is 1.5 Km. Clearly, the measurement of large targets at operationally useful frequencies leads to large outdoor facilities, thus indoor ranges are restricted to measuring smaller targets. Outdoor facilities, however, suffer the disadvantages of external monitoring, interference from external sources, and bad weather. One study contributed as much as a 35 percent increase in operating hours for the indoor range due to the weather alone (4:383). Another method of approximating a plane wave is to use a range reflector to simulate the large range separation, R, in a relatively short distance. By utilizing this approach, the compact range is capable of increasing the size of targets to be measured in an indoor facility. This study will deal with an indoor far-field range.

Background

The radar cross section of a target is an indication of the amount of power in the incident field that is intercepted by the target and scattered back to the source. It is a fictitious area which can be thought of as the geometrical area required to produce the target's return if the energy intercepted by this geometric area were re-radiated isotropically. The formal definition of the RCS, σ, is given by

$$\sigma = \lim_{R \to \infty} 4\pi R^2 \frac{|E^s|^2}{|E^i|^2}$$

where

E^i = the electric field incident on the target
E^s = the electric field scattered from the target
R = the distance between the source and target

The definition is normalized so that it is independent of the range separation between the source and the target and the level of the incident field (6:157).

The far-field, or plane wave requirement is accounted for in the above definition by the limiting process as R approaches infinity. In an actual measurement range, tolerance standards are set for acceptable amplitude and phase variations of the wavefront. The far-field range relies on a large range separation to yield a plane wave with acceptable amplitude and phase variations.

The definition of RCS also assumes the target to be in free space, which is also an impossible condition to perfectly duplicate in an actual measurement system. Radar returns from sources other than the target are unwanted signals and represent sources of error. With the indoor range, the unwanted returns are caused by scattering from the walls, the target support structure, the floor, and even coupling between the transmit and receive antennas. Add to these all the possible multiple interactions between these scatterers and the number of unwanted returns quickly becomes very large.

These unwanted returns can be partially removed in an indoor range by attenuation, vector subtraction, or hardware (range) gating. Applying Radar Absorbing Material (RAM) to the surfaces which are unwanted scatterers, such as the walls of the range, attenuates the undesirable energy and improves the approximation of free space. The other two techniques for improving the free space condition, vector subtraction and time gating, are indirect methods, and will be discussed later.

AFIT Far-Field Range

The heart of AFIT's RCS measurement facility is the Hewlett Packard Network Analyzer HP 8510B. This recently acquired piece of equipment measures the radar return (relative to a reference signal) and is used to control the associated hardware necessary for the RCS measurement. The range can accommodate measurements from 6 to 18 GHz, and is powered by an HP 8340B Synthesized Sweeper. The chamber is lined with eighteen inch pyramidal absorber, and uses a conical ogive target support.

The radar cross section is a complex function of many variables, hence there are a number of ways to display it. The AFIT far-field range will be able to analyze a target's RCS in various ways. One of these, a common method known as a "pattern cut", is to rotate the target in some plane through 360° at a fixed frequency. This measurement reveals the dependence of RCS on the aspect, or viewing angle. Another measurement which will be available is the "frequency response" of the target's RCS. This is a measurement through a range of frequencies at a fixed aspect angle, and yields both the amplitude and phase of the RCS as a function of frequency. The complex frequency domain data can be transformed to the time domain via an Inverse Fourier Transform to obtain a temporal view of the target's return. These techniques will be explained further in Chapter III.

Problem statement

The purpose of this thesis is twofold. The first objective is to complete the development of the AFIT far-field radar range; particularly to install the recently acquired equipment and automate the measurement process with proper calibration procedures. The chamber will then be used to investigate the effect of a metallic versus a transparent canopy on the total RCS of an aircraft.

Approach

The first task is to upgrade the instrumentation used in the AFIT chamber. This will involve writing the software necessary to fully utilize the measurement capabilities of the newly acquired network analyzer. These measurements include pattern cuts and target frequency responses. The ability to measure the amplitude and phase of the frequency response brings about the requirement to perform a complex calibration. The complex calibrated frequency response can then be used to compute the band-limited impulse response of the target (time domain view). These are all tasks which the software must accomplish. The software will also perform a vector background subtraction and implement a 'software range gate' to minimize the undesired signals. This first task will include the software, validation tests of the system, and an assessment of system sensitivity, or noise floor.

The second task of this research is to examine the scattering from metallic versus transparent canopies. Measurements will first be made of small-scale models of fighters. These measurements will show the effect of metallic versus transparent canopies on the total aircraft RCS at a specific azimuth angle. The measured results of the scale models must be scaled in order to relate them to the full-size aircraft. For example, a 1/33 scale model measured at 10 GHz is equivalent to the full-size aircraft measured at an effective operating frequency of .3 GHz.

Measurements will also be made on a test body which will physically isolate the cockpit/canopy effect from the aircraft. The test body, which will be discussed further in Chapter V, is intended to have a very low RCS so that the object of interest, in this case the cockpit/canopy, will be the only scatterer. In addition, the test body measurements will result in a higher effective operating frequency, since the cockpit/canopy can be as large as the entire scale model mentioned in the above example.

As mentioned earlier, in an ideal RCS measurement, a target would be in free space and would be illuminated by a perfect plane wave. One objective of the next chapter is to quantify how well the AFIT measurement range approximates these ideal conditions.

The AFIT Anechoic Chamber

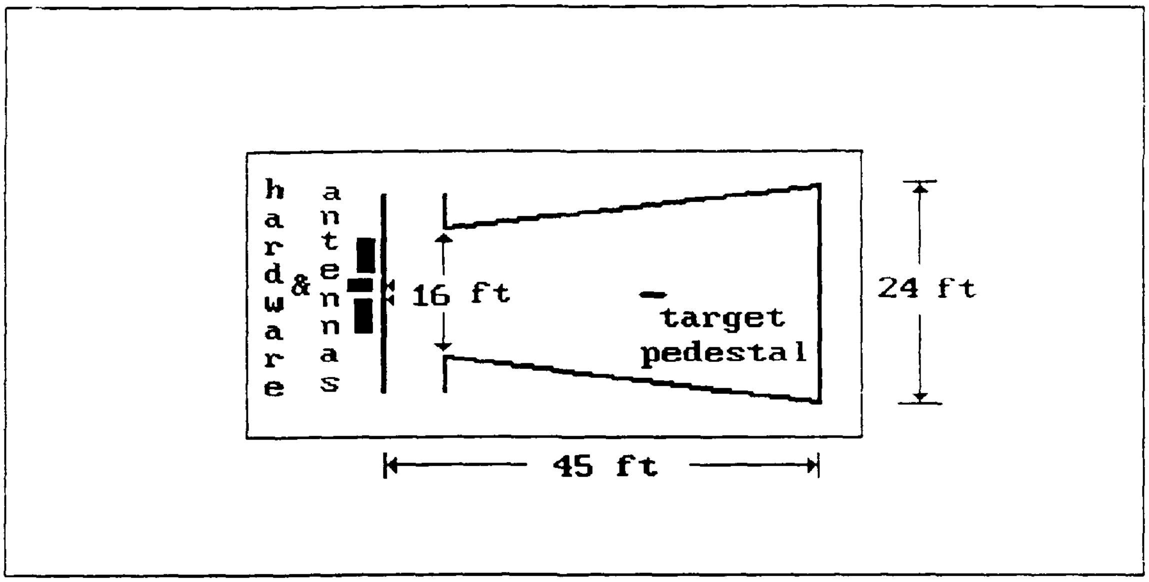
This chapter describes the hardware and physical layout of the AFIT far-field RCS measurement range. Also discussed are the approximations of the conditions assumed in the definition of RCS. These conditions are that of an incident plane wave and of a target in free space. These conditions will be quantified to some extent.

Physical Layout

The RCS measurement range is part of AFIT's Advanced Technology Laboratories located in Area B at Wright-Patterson AFB. The range was built in the confines of Building 168, which presented the primary restrictions on the dimensions of the anechoic chamber. A sketch of the measurement range, shown in Figure 2-1, reveals the main features of the measurement chamber.

The most outstanding feature of the anechoic chamber is its tapered design. The chamber was constructed several years ago when such a taper was thought to suppress specular wall reflections. Measurements from Swarner (8:   ) and calculations from Joseph (3:   ), however, have shown that the pyramidal absorber material used to line the walls is not a specular scatterer. The question of optimum chamber design is outside the scope of this study.

The length of the room is 45 feet, while the crossrange distance varies from 16 feet at the front to 24 feet at the

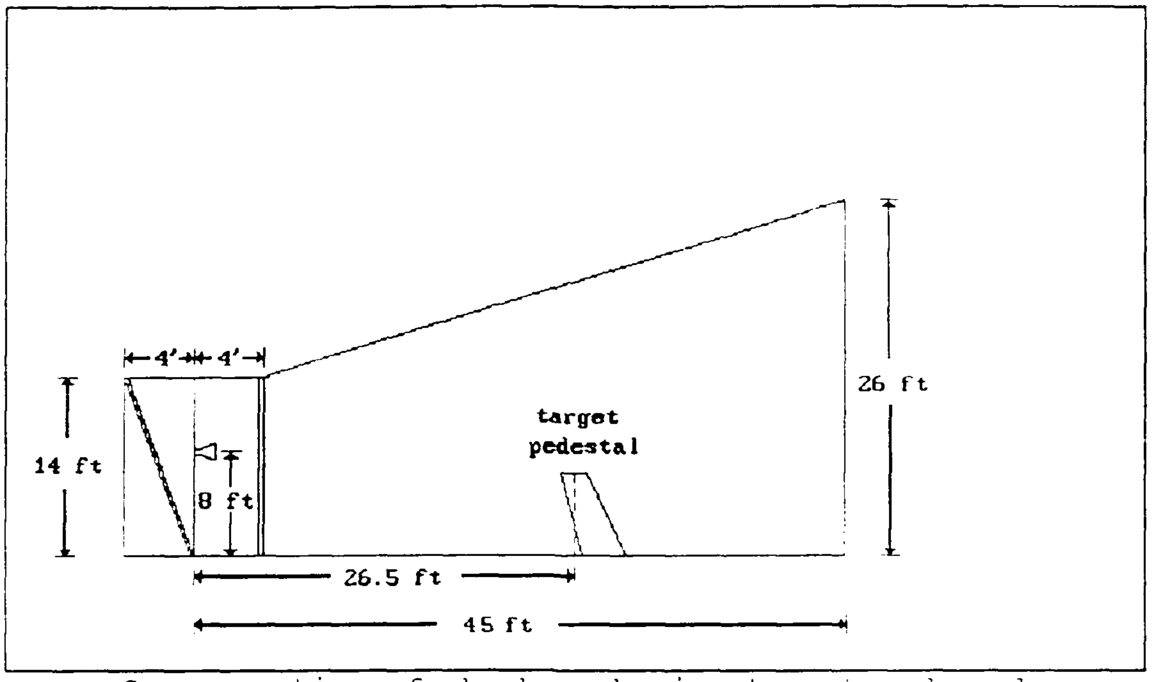


AFIT range floor plan
Figure 2-1

rear of the chamber. The ceiling is canted upward from a height of 14 feet at the front to 26 feet at the back. The two entrances into the chamber are located on the right and left sides towards the front of the chamber. A cross-section of the measurement chamber is shown in Figure 2-2.

The center of the target mount, or pedestal, is 26.5 feet from the front wall and centered in the cross-range dimension. The pedestal is a conical ogive column made of metal and stands 7.5 feet high. Its shape and orientation with respect to the incident wave are designed to have a very low RCS while maintaining the ability to support and rotate a target.

The microwave energy is transmitted into the chamber by a pyramidal horn antenna, and the return signal is collected by an identical receiving antenna. The antennas are mounted



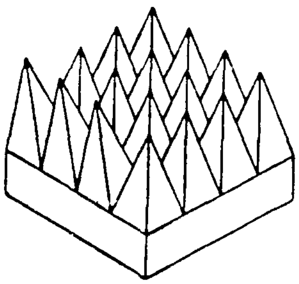
Cross-section of chamber showing target pedestal
and antennas
Figure 2-2

adjacent to one another and separated by two inches in a circular cavity on the front wall of the chamber. The antennas are centered in the cross-range dimension and are at a height of eight feet above the floor. The antennas are mounted such that the faces of the antennas extend two inches beyond the front wall of the chamber.

The walls, ceiling, and floor of the chamber (with the exception of the walk-way to the target pedestal) are lined with 18 inch pyramidal Radar Absorbing Material (RAM). A block of pyramidal absorber is shown in Figure 2-3.

This RAM is a carbon impregnated urethane foam. The 4'x 4' blocks are glued to the conducting ceiling and walls of the chamber, and placed on the tile floor of the chamber.

The RAM acts as a geometric transition from non-conducting free space to the conducting walls and ceiling. RAM is also placed to hide the base of the target support pedestal.



Pyramidal Radar Absorbing Material (RAM)
Figure 2-3 (6:252)

Hardware

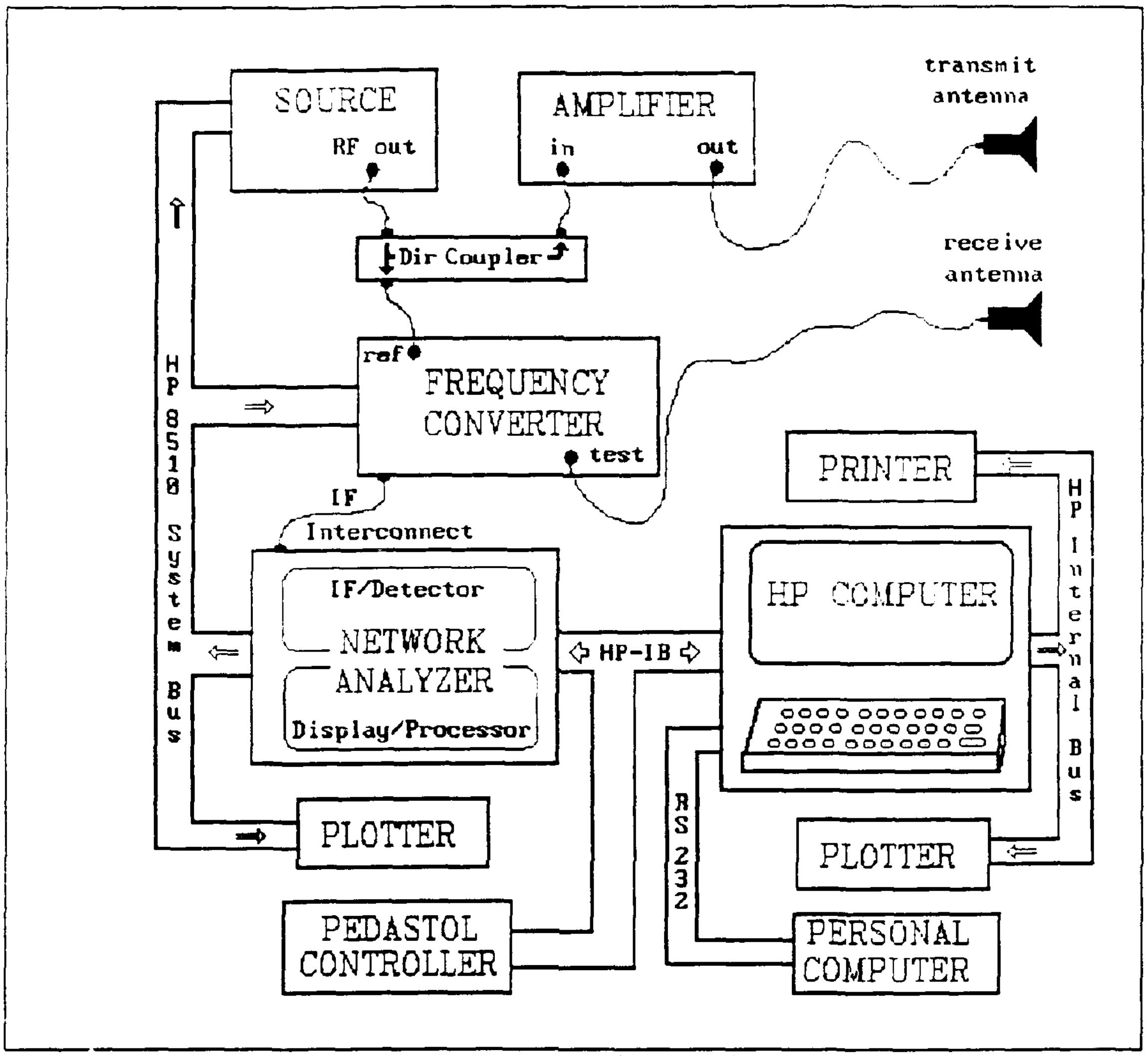
The next task is to describe the instrumentation used to perform RCS measurements in the AFIT range. A schematic of the hardware set-up is provided in Figure 2-4.

Source/Amplifier. The transmitted signal for the RCS measurement is a continuous wave (CW) microwave radio frequency signal generated by the HP 8340B Synthesized Sweeper. The sweeper output is fixed at 0.0 dBm. The accuracy of the source at this output level is ±1.5 dB. The signal is passed through a directional coupler, and then sent to the HP 8349B Microwave Amplifier where the level is boosted to 24 dBm for all measurements. At this relatively low power output level, the stability of the amplifier is rated at ±1.25 dB (2:Sec 1-11).

Antennas. The purpose of the antennas is to transmit the illuminating energy and receive the scattered energy. Because the source is producing a continuous signal (as opposed to a pulsed-CW system), separate transmit and receive antennas are required. The antennas used in this study cover the frequency range of 6 GHz to 18 GHz. The main lobe of the radiation pattern provides nearly uniform illumination of the target.

Frequency Converter. The role of the HP 8511A Frequency Converter is to convert the RF test and reference signals to IF while preserving the relative amplitude and phase of the two signals. This function is not performed perfectly; however, any frequency-dependent distortion introduced will later be eliminated in the calibration process. The frequency conversion of the RF signal is to an IF of 20 MHz which is then passed to the network analyzer for measurement.

Network Analyzer. The heart of the measurement system is the HP 8510B Network Analyzer (NWA). The HP 8510 is actually composed of two instruments which operate on the incoming data from the frequency converter. In the first step, the HP 85102 IF/Detector converts the 20 MHz signal to 150 KHz where the synchronous detectors determine the real and imaginary parts of the test signal relative to the



Hardware configuration
Figure 2-4

reference signal. The relative amplitude and phase data is then sent to the HP 85101 Display/Processor for data processing and conversion to one of the display formats.

The entire system can be controlled from the front panel of the network analyzer. The source, frequency converter, pedestal controller, and peripherals such as plotters can be linked to the NWA via the HP 8510 System Bus. In the configuration used at the AFIT range, however, the measurement process is automated by a computer.

System Controller. The measurement procedure is directed by the HP 9000 Series 236 Computer. The computer controls the entire system either directly through the HP-IB or indirectly through the HP 8510 System Bus via the network analyzer. The computer and NWA share the processing and calibration functions as prescribed by the software. These tasks and the software will be discussed in Chapter III.

Pedestal Controller. The servo-mechanism which rotates the target pedestal is controlled by the Newport Corporation 855C Controller. This controller is directed by the HP computer.

Peripherals. There are several options for obtaining hardcopies of the RCS data. A printer is hardwired to the HP computer for obtaining program listings or screen dumps. A plotter is also hardwired to the HP computer to get formatted RCS plots. Another plotter is dedicated to the NWA to obtain a copy of whatever data is on the NWA screen. Finally, a personal computer is connected to the HP computer via an RS232 link so that data files can be sent to this second computer for off-line processing.

The final objective of this chapter is to evaluate how well the AFIT RCS range duplicates the conditions assumed in the definition of RCS of an incident plane wave and a target isolated in free space. While the software which directs the measurement procedure is very much a part of AFIT's anechoic chamber, its impact on the final result will be addressed in Chapter III.

Target Zone

The definition for the RCS, σ, assumes that the distance between the target and the source approaches infinity to enforce plane wave illumination. (The target is assumed to be a small scatterer in the far zone of the source.) One question to be answered, then, is how close is the incident field in the measurement chamber to a plane wave. The other assumption in the definition that the target is in free space prompts another question of how well the measurement simulates a target in free space. Both of these questions are addressed next.

Incident Plane Wave. In comparing our incident field to an ideal plane wave, three parameters are considered: crossrange amplitude variation, crossrange phase variation, and downrange amplitude variation. Ideally, all three are zero. In general, the allowable variation in these parameters depends on the type of target being measured, the required accuracy of the RCS data, and the type of processing to be performed on the RCS data. For this thesis effort (and commonly used in similar measurements), a 1 dB downrange and crossrange amplitude variation, and a $\pi/16$ radian crossrange phase variation will be chosen as allowed limits. These limits define a region in space called a target zone, in which the incident wave is acceptably similar to a plane wave. The following paragraphs will use these three parameters to determine the target zone, or maximum size of the target.

First, consider the downrange amplitude variation. Let R be the distance from the amplitude and phase centers of the antennas to the target zone, and assume R is large enough so that the amplitude of the incident field varies as 1/R in the target zone (a very good assumption). This leads to the relationship

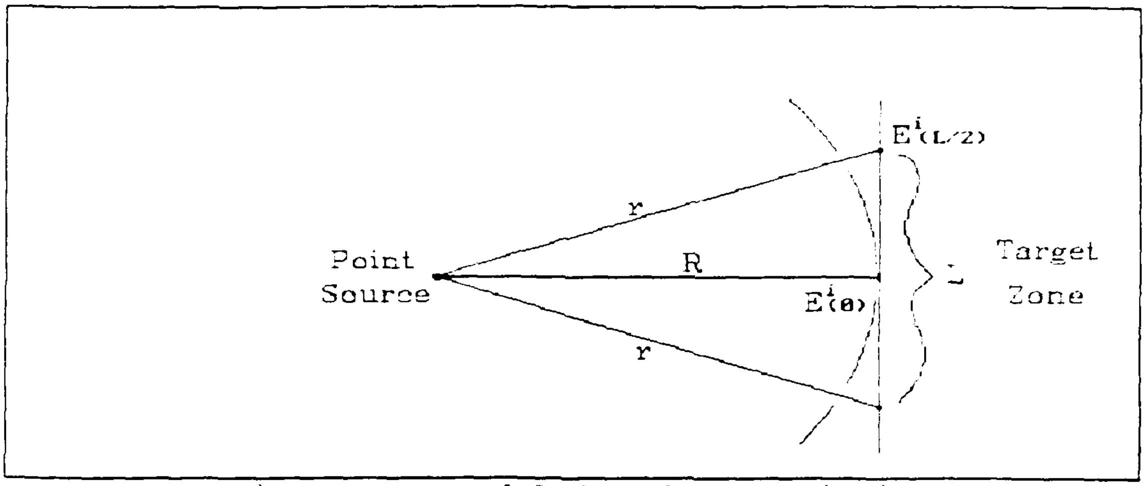
$$D=R/8.2 \qquad 2\text{-}1$$

where D is the downrange extent of the target zone.

The next parameter to be considered is the crossrange phase variation. Assume that the source is a point source as shown in Figure 2-5. (A more rigorous analysis would consider the actual antenna used, but would yield virtually identical results.) Assume that $E^i(L/2)/E^i(0)=Ae^{-j\phi}$, so that A and ϕ are the crossrange amplitude and phase variation, respectively. By simply accounting for the different phase paths from source to target zone center and from source to target zone edge, one can show that $\phi=\pi/16$ radians leads to,

$$L\leq\tfrac{1}{2}(\lambda R)^{1/2} \qquad 2\text{-}2$$

where L is the crossrange extent of the target zone and λ is the operating wavelength. By the same argument, the

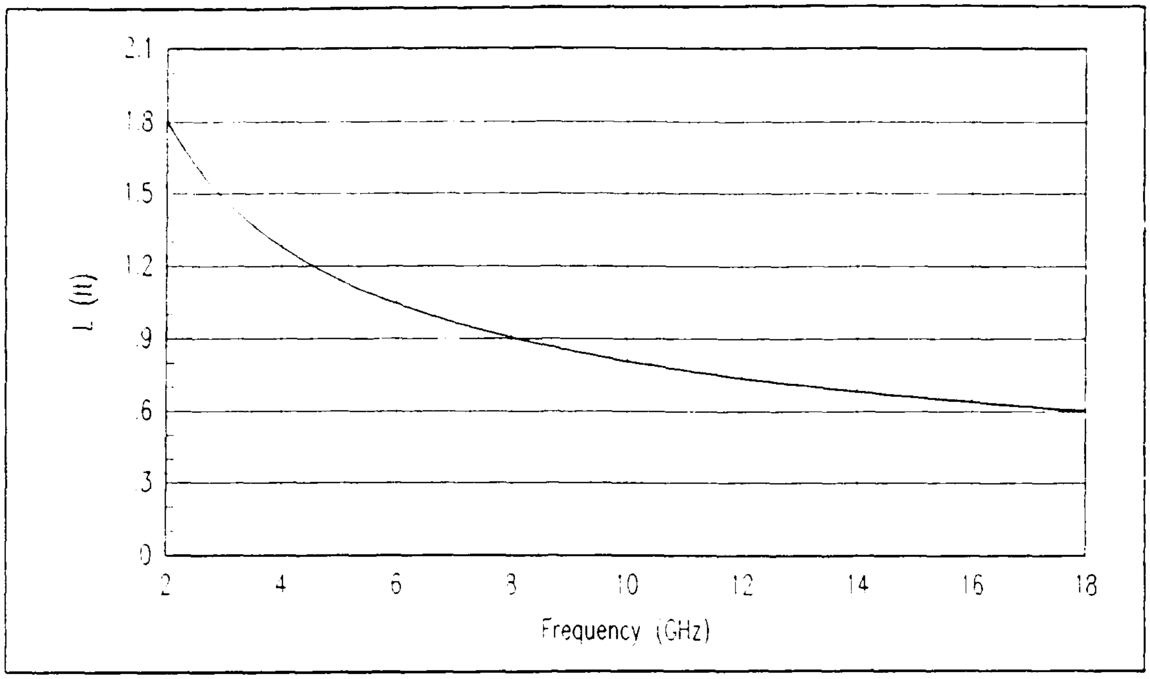


Point source model for phase variation
Figure 2-5

vertical extent of the target zone is also given by equation 2-2, hence the target zone can be visualized as a cylinder of diameter L and length D centered on the target mount.

Finally, when considering the crossrange amplitude variation, the point source model is inadequate. Its application would result in $L \approx R$. A more rigouous analysis where some antenna is chosen must be carried out. This would result in a limit on L which is less restrictive than that set by the allowed crossrange phase variation. The dimensions of the target zone, therefore, are determined from equations 2-1 and 2-2. More information on this subject can be found in (5:920-928).

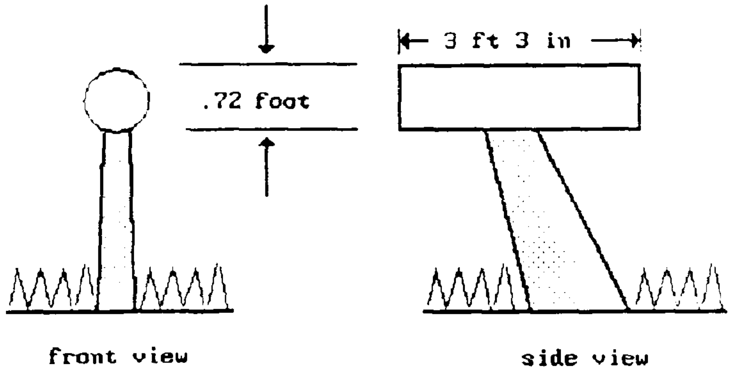
Recalling the fixed range separation in AFIT's chamber of 26.5 feet, equation 2-1 yields a value of 3.2 feet for the downrange extent of the target zone. Figure 2-6 displays L versus frequency for a range of 26.5 feet.



Crossrange extent of target zone versus frequency
Figure 2-6

The maximum crossrange extent of the target zone is clearly limited by the highest operating frequency. Currently, the maximum frequency of operation in AFIT's range is 12.4 GHz, which restricts the crossrange extent of the target zone to 0.725 feet, or 8.7 inches. The crossrange extent of the target zone is 0.6 feet, or 7.2 inches if the upper frequency is 18 GHz. Now that the target zone is fully specified, the front and side views of the target pedestal and the cylindrically-shaped target zone are shown in Figure 2-7.

Target in Free Space. To accurately produce the RCS of a target, the range must be able to measure the return from the target as if it were in free space. Any returns from other than the target will incorrectly affect the result.



Target zone dimensions for upper frequency of 12.4 GHz
Figure 2-7

The goal of the AFIT far field range, then, is to minimize these erroneous returns. A parameter used to evaluate how well a chamber reduces the unwanted returns is called the noise floor.

The noise floor is the noise level remaining after range gating and vector subtraction have been performed. It determines how accurately, if at all, low RCS targets can be measured. In a well designed measurement system, receiver noise is below the "noise floor", so that receiver noise is not the overriding source of noise in the measurement system. The measured noise floor of the AFIT range is at least -60 dBsm between 8 GHz and 12.4 GHz. The accuracy of the amplitude of a measurement, however, is directly related to the Signal to Noise Ratio (SNR). This means, for example, if a measurement accuracy of ± 0.5 dB is desired, the target should have a minimum RCS at least 10 dB higher than the measured noise floor, or -50 dBsm.

In summary, the target zone of the chamber was identified as a 3.3 foot cylinder with a diameter of 0.72 feet. The noise floor of the chamber was measured at -60 dBsm between 8 GHz and 12.4 GHz. The next chapter discusses the software which automates the measurement process. In addition to describing the structure of the program and the options it offers the user, Chapter III will explain how the measurements are taken and show that these are valid RCS measurements.

AFIT RCS Measurement Software

An integral component of the AFIT far-field measurement range is a software package called AFIT RCS Measurement Software (ARMS). The code was written in HP BASIC to run the HP 9236 computer which serves as the controller for the measurement range. Although the most obvious purpose of ARMS is to automate the range instrumentation, the software also directs the measurement procedures and, more significantly, calibrates the raw data and performs vector background subtraction. There is also a post-processing option via the network analyzer. The purpose of this chapter is to explain these capabilities and provide a brief description of ARMS.

ARMS Structure

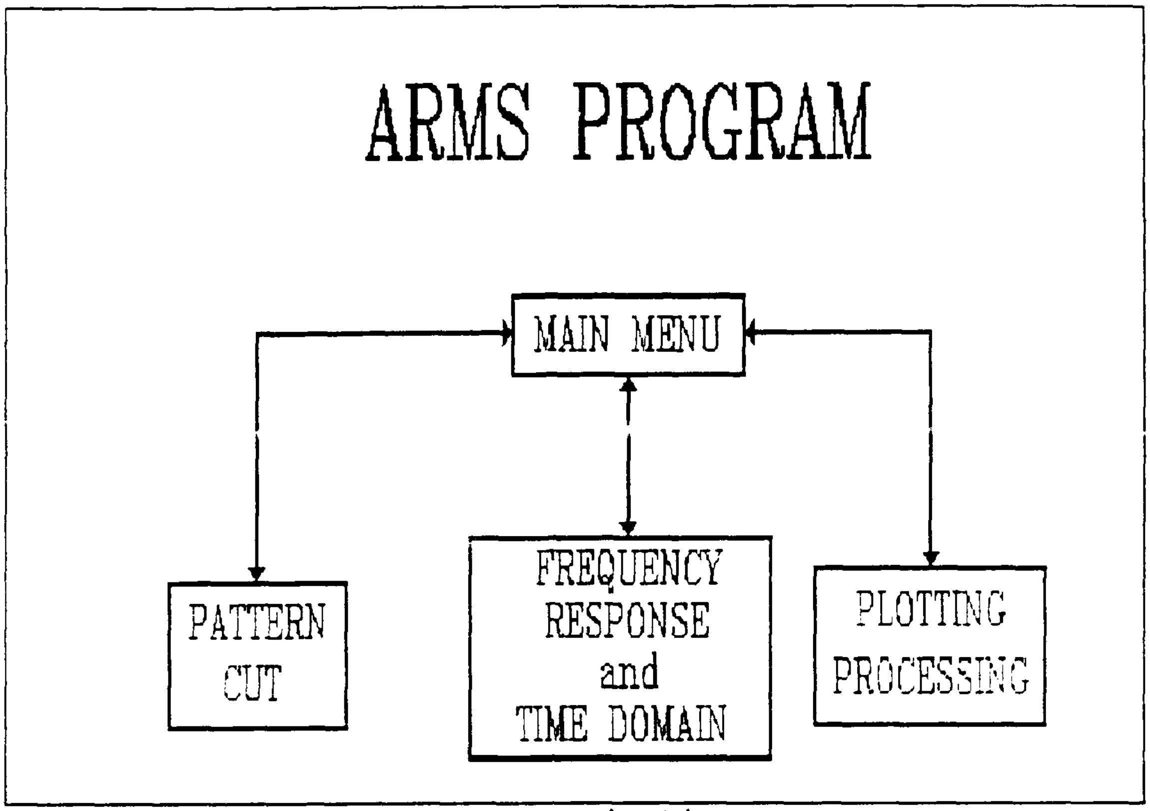
The ARMS program is a compilation of three major subroutines. The first two perform pattern cuts and frequency responses, respectively, while the third subroutine handles processing and plotting of previously measured data. A significant portion of the processing/plotting subroutine is composed of existing code written recently by AFIT faculty and staff members. More detailed information regarding the architecture and operation of the software may be obtained from the flow charts provided for each subroutine (listed in Appendix A), or from the code itself (listed in Appendix B). The flow charts provided in this chapter are extremely simplified in order to aid in the discussion of the measurement procedure.

The overall organization of ARMS is shown in Figure 3-1. The motivation behind this structure is to separate the measurement activity from the plotting and processing activity. This organization was selected in part because of the ability and preference to transfer the calibrated data files from the HP computer to a Zenith computer, whose plotting and processing options are not nearly as limited. This approach will also save time since it frees the range for further measurements.

Calibration

This section will explain the formula used in ARMS to produce the calibrated RCS of a target for a pattern cut or frequency response. A discussion of the limitations of the formula and how it applies to the two measurements will follow.

In order to determine the RCS, the formula must produce the quantity $r(E^s/E^i)$, where E^s is the scattered field of the target, E^i is the incident field at the target, and r is the range separation from antennas to target. This quantity, which is the basis of the definition of RCS (reference equation 1-1), assumes a plane incident wave and, for now, neglects the 4π constant.



ARMS organization
Figure 3-1

Consider the exact solution of the scattering from a sphere, E^s_{SE}. The solution can be written in terms of the incident field and the range separation as shown below

$$E^s_{SE} = E^i \frac{F}{r}$$

where F is some known complex scattering function. Note that two of the elements in the definition of RCS, r and E^i, are present in the exact solution of the sphere, but are inverse to the same elements in the desired quantity. Solving for F corrects the inverse problem, and since it is known exactly, F will be used to calibrate the desired result. Finally, multiplying F by the quantity E^s/E^s_{SM} results in a very good approximation to the desired quantity in the definition of RCS. As will be shown later in this chapter, since the measured sphere return, E^s_{SM}, is close enough to the exact solution of the sphere, E^s_{SE}, the two quantities will cancel to result in the expression shown in equation 3-1.

$$\left(r\frac{E^s_{SE}}{E^i} \right) \times \left(\frac{E^s}{E^s_{SM}} \right) = r\,\frac{E^s}{E^i} \qquad \text{3-1}$$

where E^s= the measured scattered field from the target (with the background subtracted)

E^s_{SM}= the measured scattered field from the sphere (with the background subtracted)

The formula, then, used in ARMS to calculate the calibrated RCS in the frequency domain is given by

$$\sigma = 4\pi \left| F\frac{E^s}{E^s_{SM}} \right|^2 \qquad \text{3-2}$$

which, ideally is equivalent to

$$\sigma = 4\pi r^2 \left| \frac{E^s}{E^i} \right|^2$$

The quality of the measured sphere and target returns dictates the accuracy of the measurement. The software performs complex vector background subtraction on these returns in an attempt to duplicate the free space condition inherent in the definition of RCS. (Recall that the far-field condition has already been assumed, and is approximated by imposing limitations on the permitted phase and amplitude variations of the incident field.) The subtraction, however, cannot include the interactions between the target and the target mount, or between the sphere and the sphere mount, and so on, because these interactions are not present in the background measurement. Note that the formula for the calibrated RCS given in equation 3-2 can be used for a single frequency, as in a pattern cut, or used repeatedly through a range of frequencies, as in a frequency response.

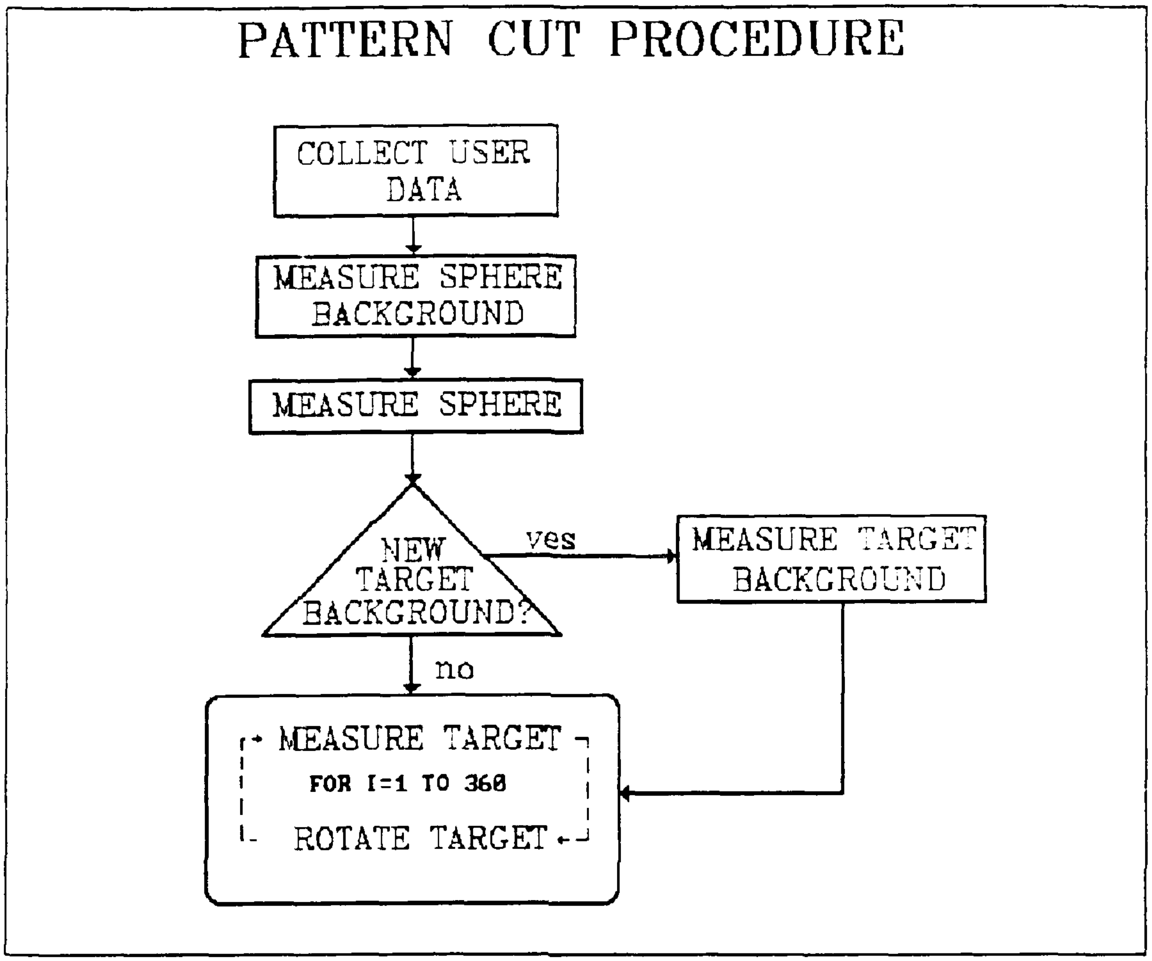
The next task is to describe the procedure for performing the two measurement options available to the user: the pattern cut and the frequency response. A pattern cut is a representation of the RCS of a target as a function of aspect angle. The data is taken at a single frequency while the target is rotated through 360 degrees. A frequency response shows the RCS of a target as a function of frequency at a fixed azimuth angle. This allows for the calculation of a bandlimited impulse response, which is a time domain view of the target scattering. For both options, there are four measurements required to compute the RCS. They are the reference sphere background, the reference sphere, the target background, and the target. Also, an appropriate amount of averaging is used for each type of measurement, and the user can select the width of a pre-measurement gate which defines the range gate for which data is collected. The pattern cut is the first measurement option to be discussed.

Pattern Cut Procedure

For the pattern cut, ARMS directs the network analyzer to record the magnitude (in dBsm) of the complex return for all measurements. For this discussion, refer to the flow chart of the measurement procedure for the pattern cut which is shown in Figure 3-2.

First, the user is prompted to input information needed for the pattern cut, such as the operating frequency, gate width, and polarization. The user then measures the return of the reference sphere background. This background is composed of the room and the mount which supports the sphere. The network analyzer places this return in the network analyzer memory. The next measurement needed is the return from the reference sphere. After this measurement is made, the network analyzer subtracts the sphere background return from the sphere measurement to come up with the free-space measurement of the reference sphere. As explained earlier, the background subtraction is performed to comply with the free space condition in the definition of RCS. Note that the sphere and sphere background measurements are taken at one position only.

The third measurement is of the target background. If the target background is identical to the reference sphere background, the measurement can be skipped, as ARMS will



Measurement procedure for a pattern cut
Figure 3-2

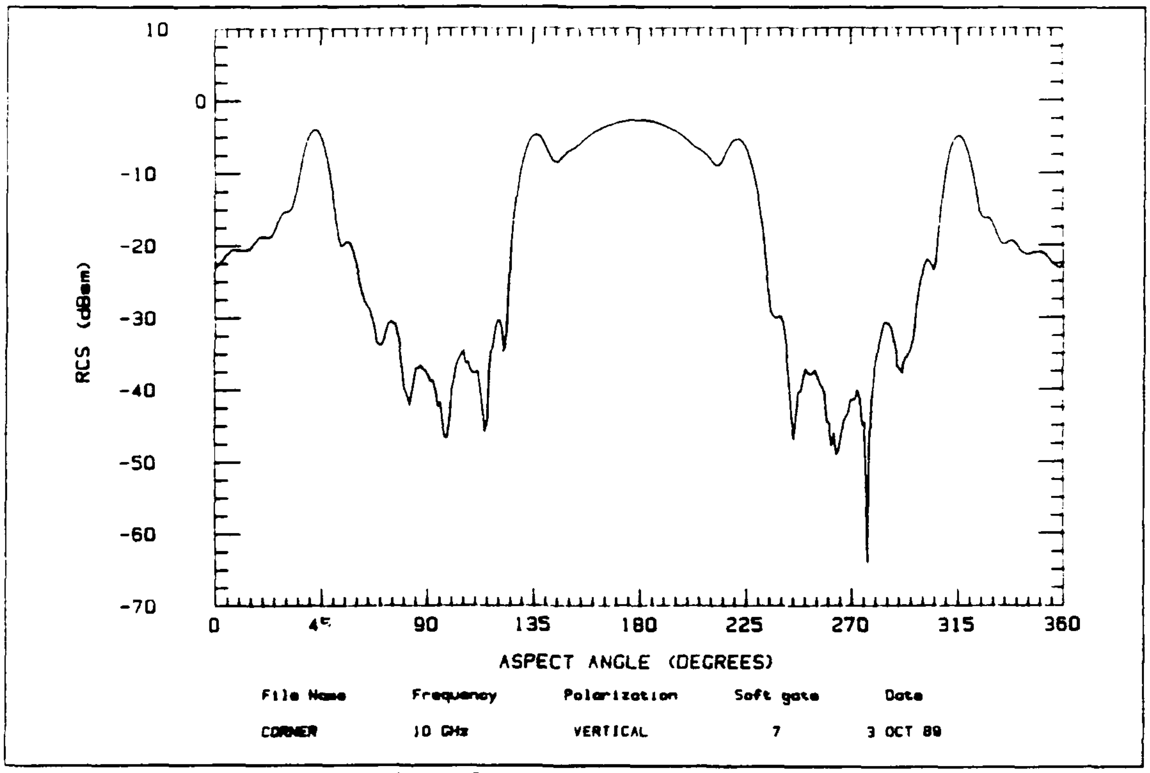
substitute the sphere background return for the target background return upon subtraction. If the target background is different, care should be taken that the target background, or mount, is symmetrical in the azimuthal plane since the mount will be rotated in a pattern cut. As before, the target background return is placed in the network analyzer memory where it will be subtracted from the target return.

When the target background option is resolved, the last measurement is of the return from the target. At each degree, the target return is measured and sent to memory where the target background is subtracted. The free-space target return is then stored in the first row of a 1 x 360 dimensioned array. The positioner then rotates the target mount to the next position and the process is repeated until the array is filled. This sequence of measurements is intended to minimize the possibility of moving something in the chamber once it has been measured, hence introducing error in the measurement procedure.

The final step in producing a pattern cut is to calculate the RCS for each of the 360 data points. The formula which calculates RCS for a pattern cut uses an approximation which makes it slightly different from the formula given in equation 3-2. The high frequency approximation for the return of a sphere, πa^2, (a is the radius of the sphere), is used instead of the exact solution for the scattering from a sphere. The effect of this simplification on the pattern cut, however, is simply a uniform shift in the magnitude of the data. The formula used by the HP computer to calculate the magnitude of the return in decibels, is shown in equation 3-3.

$$\sigma_{\text{pattern cut}} = 10\log(\pi a^2) + [\text{Target-Target\_background}] - [\text{Sphere - Sphere\_background}] \ (\text{dBsm}) \qquad 3\text{-}3$$

After the pattern cut is complete, the result is displayed on the HP 9236 computer, with a menu which offers several options. The user can align or shift the pattern cut to a desired angle, save the result, perform another pattern cut, or return to the main menu. An example plot of a pattern cut is shown in Figure 3-3. The target is a trihedral corner reflector oriented so the maximum open face



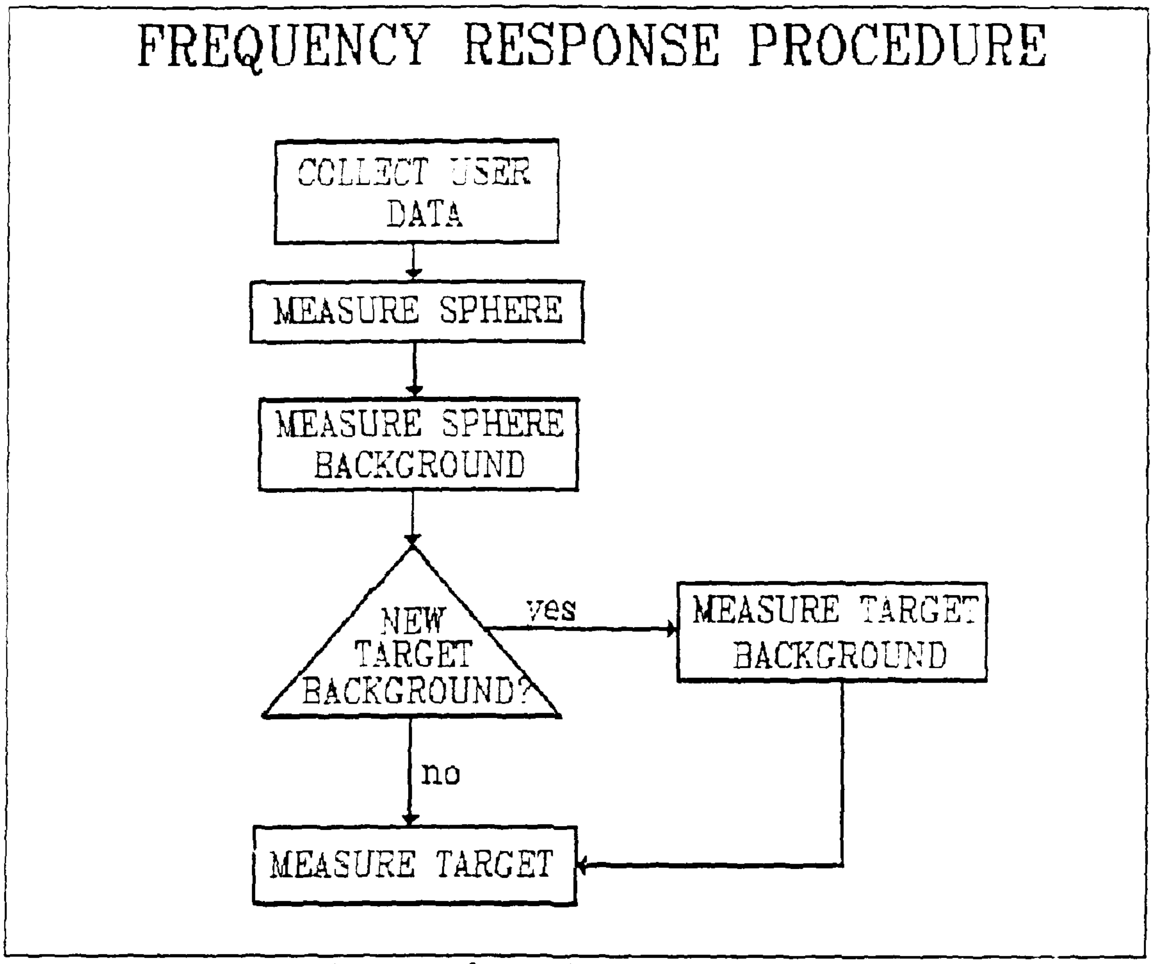
Example plot of a pattern cut
Figure 3-3

occurs at 180°. The RCS is given in dBsm, and the angular resolution of the data is one degree. The header information provided at the bottom of the plot includes the width of the software gate selected at the beginning of the measurement.

Frequency Response Procedure

A frequency response measurement displays the RCS of a target as a function of frequency at a fixed azimuth angle. For each of the four required measurements, the network analyzer samples the bandwidth of the sweep at 801 equal intervals, and records the real and imaginary components of the return in a 801 x 2 dimensioned array. ARMS implements trace averaging, where the displayed trace is a weighted average of previous traces, instead of the single frequency point averaging technique used in the pattern cut, to obtain consistent data. Figure 3-4 provides a flow chart of the measurement procedure for a frequency response.

As with the pattern cut, the first step taken by ARMS is to obtain the necessary input from the user. For a frequency response, the required information is the start and stop frequency, antenna polarization, range gate width, averaging factor, and the sweep mode of the source generator (ramp or step). The first two measurements are of the returns from the reference sphere and the reference sphere background. The network analyzer writes the complex data to arrays called Reference, and Ref_background, respectively. Next, the user is prompted to measure the target background. As with the pattern cut, if the backgrounds are the same, ARMS provides the user an option to substitute the reference

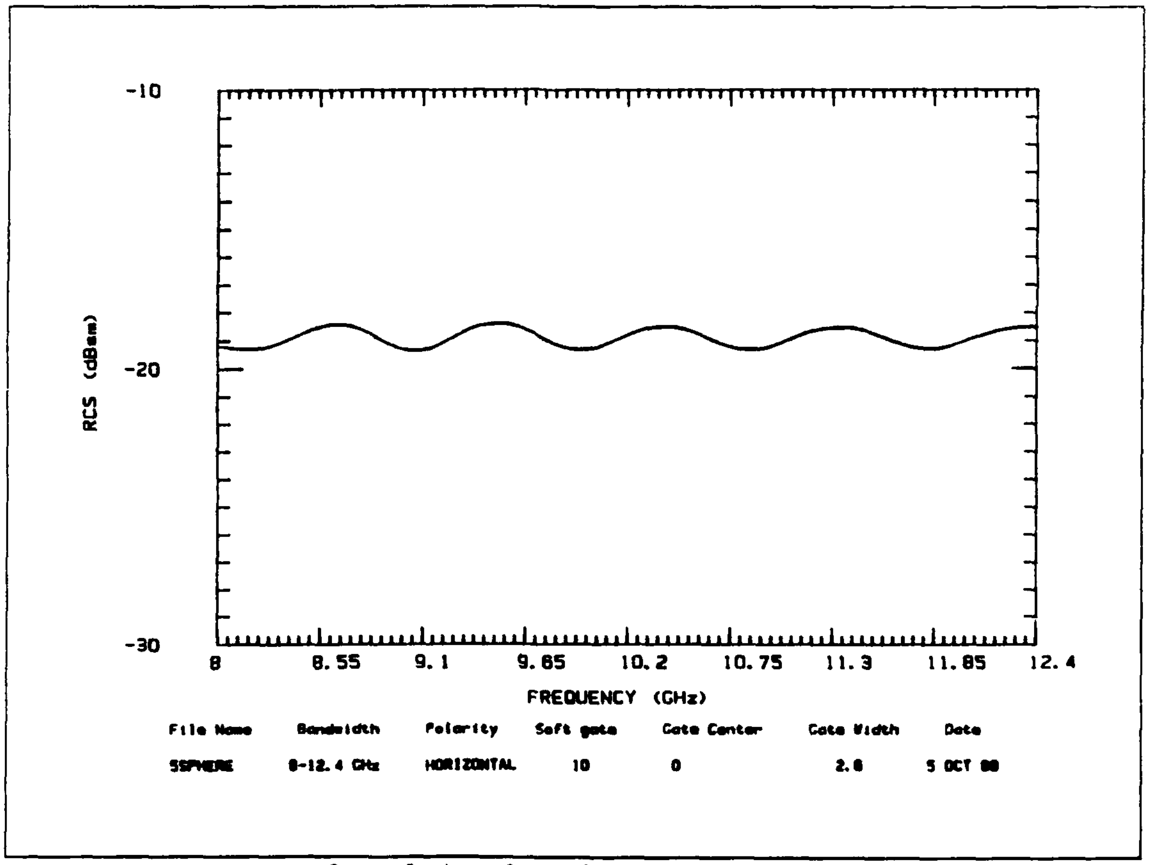


Measurement procedure for a frequency response
Figure 3-4

sphere background return stored in the array Ref_background, for the measured target background return to be stored in an array called Target_background. Finally, the target is measured and the data stored in the array named Target.

For the frequency response, ARMS performs complex vector background subtraction for the sphere and target measurements. The calibration is performed using the exact solution of the reference sphere, as indicated in equation 3-2.

A sample of a frequency response plot is shown in Figure 3-5. Note that a software gate can be applied to the calibrated frequency response data, in addition to the pre-measurement range gate, labeled 'soft gate' on the plot. The plot designates the center of the software gate, labeled 'gate center', and the width of the gate, labeled 'gate width', which is symmetric about the center. ARMS utilizes the processing capability resident in the network analyzer to set the location and width of the secondary gate.



Example plot of a frequency response
Figure 3-5

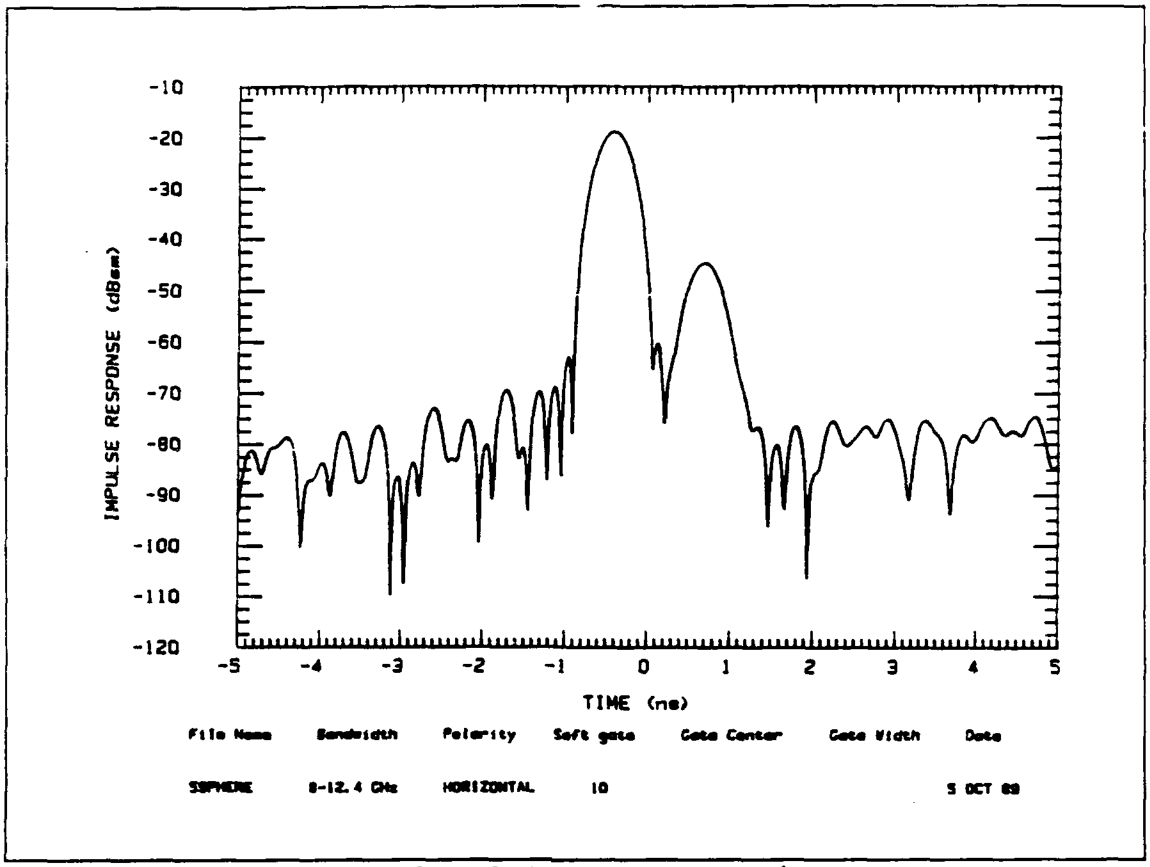
The target in the example frequency response in Figure 3-5 is a five inch sphere. The dominant contributor to the

RCS of a sphere is the specular return, which is shown in the plot to be approximately -19 dBsm. The variation of the RCS about this level indicates the presence of the creeping wave which adds in and out of phase with the specular return.

Time Domain

As mentioned earlier, the network analyzer has a feature which produces a temporal view of the RCS by transforming the frequency response data to the time domain via an inverse Fourier Transform. This view of RCS gives an indication of the downrange position of the scatterers on the target. Figure 3-6 is an example plot of the time domain view of RCS. The target is the same sphere whose frequency response is shown in Figure 3-5, but the specular and creeping wave are now isolated in time. Notice the same header information is provided for the frequency response plot and time domain view of RCS. The alias free range, impulse width, and range resolution are useful parameters which describe the time domain view and quantify the limitations due to the band-limited processing and the sampling technique used to obtain the RCS versus time data.

Alias Free Range. The alias free range, or measurement range, is the downrange distance in which a measurement can be made without encountering aliasing, which is a repetition of the response. Aliasing is a consequence of the manner in which the frequency domain data is collected. An



Example plot of RCS vs time
Figure 3-6

illustration of aliasing is provided in Figure 3-7. The network analyzer effectively converts continuous frequency spectrum data into a discrete set of data due to the sampling process at the uniform frequency points. The effect of this sampling process is that the time domain response becomes a periodic function with a period, T, of $1/\Delta f$ seconds, where Δf is the frequency spacing between samples. The frequency spacing is determined from the bandwidth of the frequency response and the number of samples taken. The alias free range, $R_{alias\ free}$, is found by multiplying the period of the repeating time domain

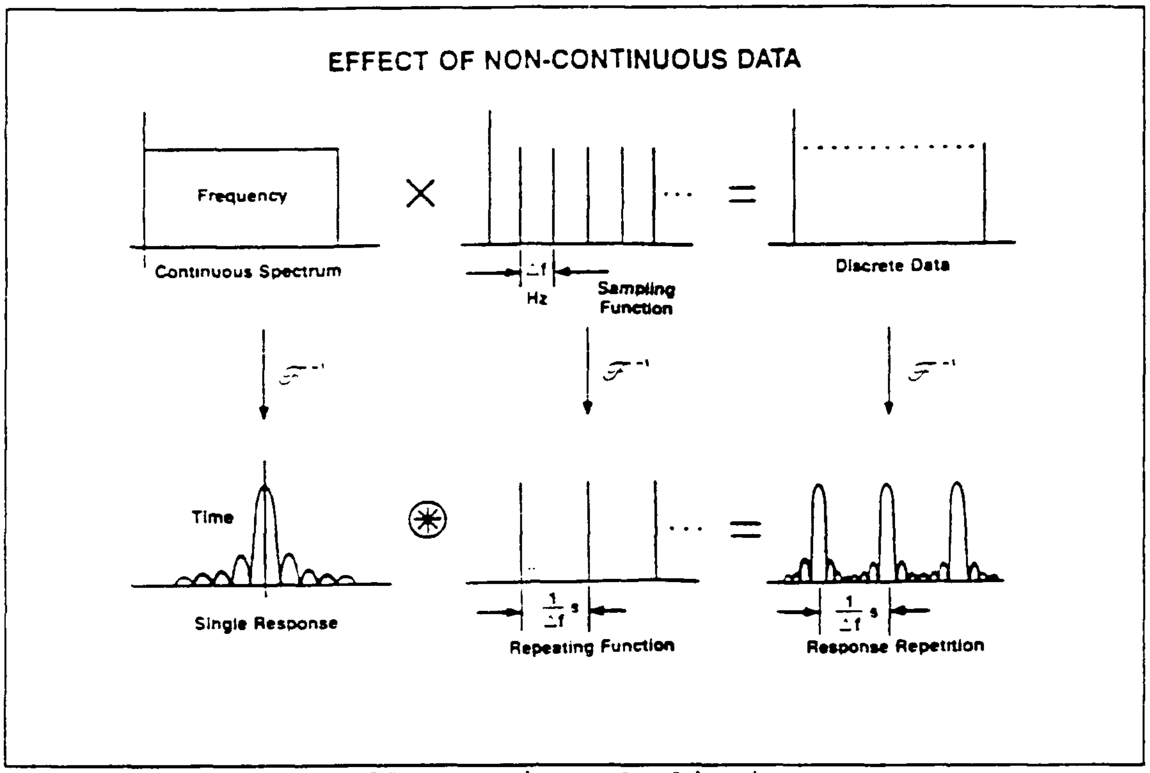


Illustration of aliasing
Figure 3-7 (1:Sec 3.5-11)

response, T, by the velocity of the wave in the medium, c, which is taken here as the speed of light in free space. Because an RCS measurement is a reflection measurement, the actual downrange distance of the target cannot exceed half of the alias free range.

$$R_{alias\ free}(\text{meters}) = \frac{1}{\Delta f\ (\text{Hz})} \times c(\text{m/sec})$$

At the AFIT measurement facility, the downrange distance before aliasing is encountered is 89.5 feet for a frequency range of 8 to 12.4 GHz and 801 sampling points.

<u>Range Resolution</u>. This parameter defines the minimum distance required to separate two responses of equal

magnitude which are close together in time. Sometimes called response resolution, the range resolution is directly related to the impulse width. The impulse width depends on the frequency range and the window selected, and is defined as the width between the half power points. For reflection measurements such as for RCS, the relationship for the impulse width is

$$\text{Impulse Width} = 0.96/f_{range}(Hz)$$

where f_{range} is the bandwidth of the frequency response, and the constant 0.96 is associated with a 'normal' window as defined in the network analyzer (1:Sec 3.5-16). (Note the difference between this definition and the approximation of the impulse width for a typical radar, which is 1/(2B), where B is the bandwidth of the pulse.) For a frequency response from 8 to 12.4 GHz, the impulse width is 0.22 nsec. This width will be wider for responses of different magnitudes.

The range resolution is found by multiplying the impulse width by the velocity of the wave, taken again as c, the speed of light. For the frequency response example given above, the range resolution is 2.6 inches. For a frequency response from 6 to 18 GHz, the range resolution improves to slightly less than one inch.

Display Resolution. The display resolution determines the ability to determine the location of a response in the time domain. This parameter depends on the time span on the display and the number of data points as shown below,

$$\text{Display Resolution} = t_{span}/(\text{no. of points}-1)$$

where t_{span} is the time span on the display. For measurements made at the AFIT range, the bandwidth for a frequency response will always be sampled 801 times, and the time domain display will go from -5 to 5 nsec, so a time domain response can be located with a resolution of 12.5 picoseconds on the display. Obviously, the time domain display resolution can be improved by simply narrowing the time span on the display.

Software Gate

A time gate can be applied to the time domain data of a frequency response measurement. This is accomplished from the Plotting and Processing branch of ARMS. The gate acts like a time bandpass filter which mathematically eliminates responses outside the gate. ARMS allows the user to select the position of the center of the gate and a symmetric gate width. After the gate is activated in the time domain, the network analyzer performs a Fourier Transform of the gated time domain data to obtain the new frequency response data. It is noted here that the automated processing available via ARMS represents a fraction of the processing options that exist in the network analyzer. (For more information, see reference (1:Sec 3.6).)

Performance Validation

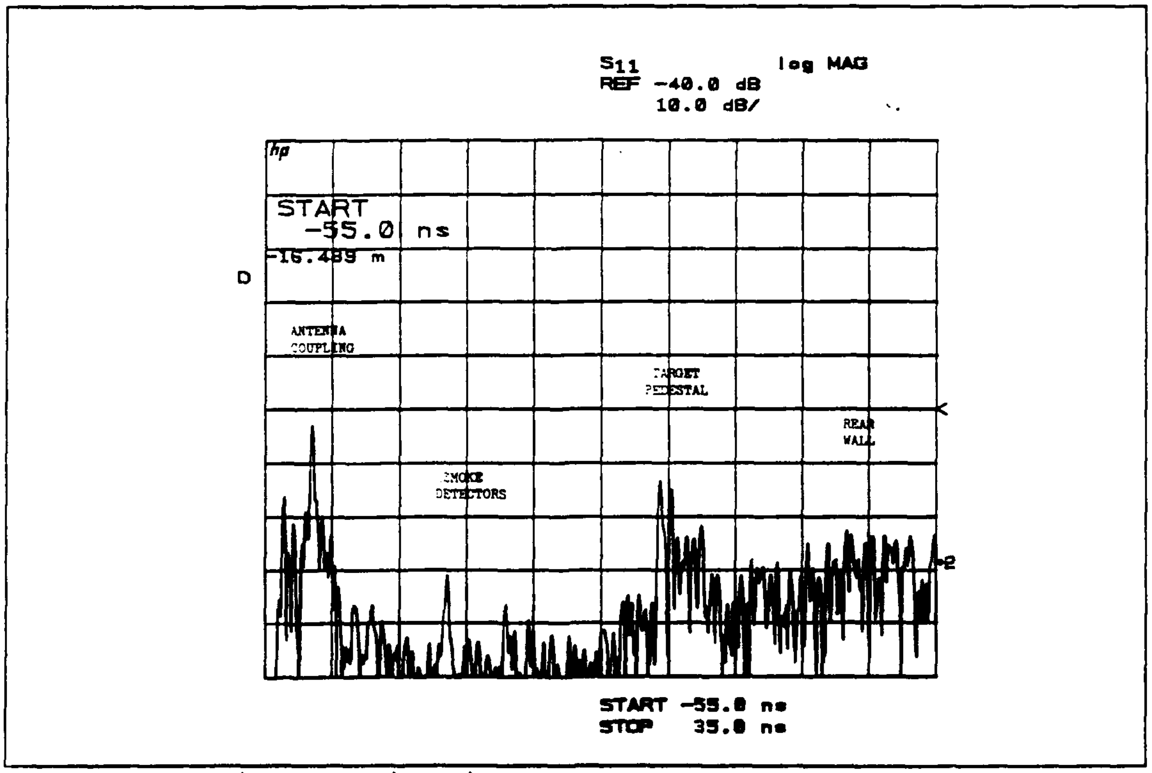
The purpose of this chapter is to validate the performance of the AFIT far-field measurement range, and demonstrate the analytical procedure and type of information obtainable using the ARMS software. The first step is to evaluate the measurement procedure and the performance of equation 3-2, which ARMS uses to determine the RCS of a target. This could be accomplished by comparing measurements of simple objects, such as flat plates or a cylinder, with the theoretical RCS of the target. Obviously, the inherent limitations of a measurement made in an indoor measurement range (due to the imperfection of the far field and free space approximations) are not considered in the theoretical predictions. However, with proper attention to measurement and processing details, one can achieve agreement (to within graphical accuracy) between measured and predicted RCS. Another way to assess the performance of the AFIT far-field range is through comparison with measurements and processing from an established indoor RCS measurement facility. To verify the proper operation of the AFIT facility, measurements were repeated at the Wright Research and Development Center's (WRDC) anechoic chamber. This measurement facility will be briefly described later in this chapter. The presence of signals from other than the target in a measurement is a source of error, and prompts questions regarding the effect of the noise floor.

Noise Floor

The noise floor of a measurement range is defined here as the maximum level of all unwanted signals in the measurement procedure after processing. In addition to the noise introduced by the hardware, the chamber is a significant source of noise in the form of undesirable scatterers. Ideally, the return from the empty chamber (no target present) is zero, as stated in the free-space condition. In the real world, however, the empty chamber, even when carefully lined with RAM, scatters the incident field. The dominant scatterers in the AFIT chamber can be seen by viewing the scattering of the chamber in the time domain as shown in Figure 4-1.

The most dominant return seen in Figure 4-1 is actually not a scatterer, as alluded to in this discussion, but represents cross-coupling energy between the transmit and receive antennas. The next significant return may be caused by two smoke detectors whose mount and location, unfortunately, were driven by safety, as opposed to scattering considerations. Located near the center of the figure and the chamber, the target pedestal structure and associated RAM are the cause for the second largest return. Also, the interactive scattering between the target pedestal, ceiling, and walls is a source of noise. Finally, direct scattering from the rear wall is seen to be a significant scatterer.

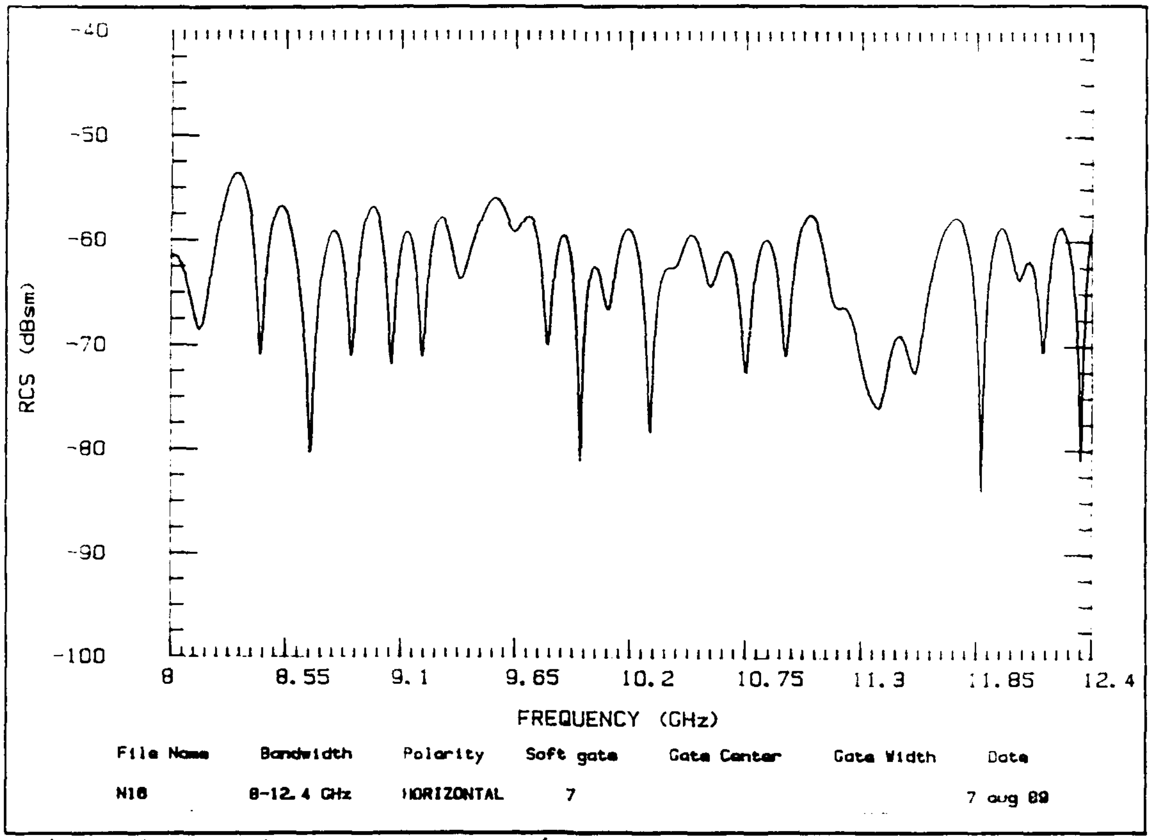
The unwanted signals can be partially removed by attenuation, vector subtraction, and hardware/software range gating. The chamber is lined with RAM which attenuates the energy as discussed in Chapter II. ARMS also utilizes vector subtraction and software range gating to reduce all unwanted signals. The scattering from stationary objects is very repeatable, hence vector subtraction does a good job of negating their impact on the measurement. A further means of reducing the unwanted signals is to apply a filter in the



Time domain view of chamber scatterers
Figure 4-1

time domain which passes *only* the *energy* corresponding to the downrange position of the desired target. Note that this technique, called time (or range) gating, also passes energy scattering from the target support structure. The effectiveness of these techniques can be determined by measuring the noise floor.

The noise floor, shown in Figure 4-2, is measured by performing a frequency response where the target measurement is actually a measurement of the empty chamber. The target background, of course, is also the same empty chamber. The



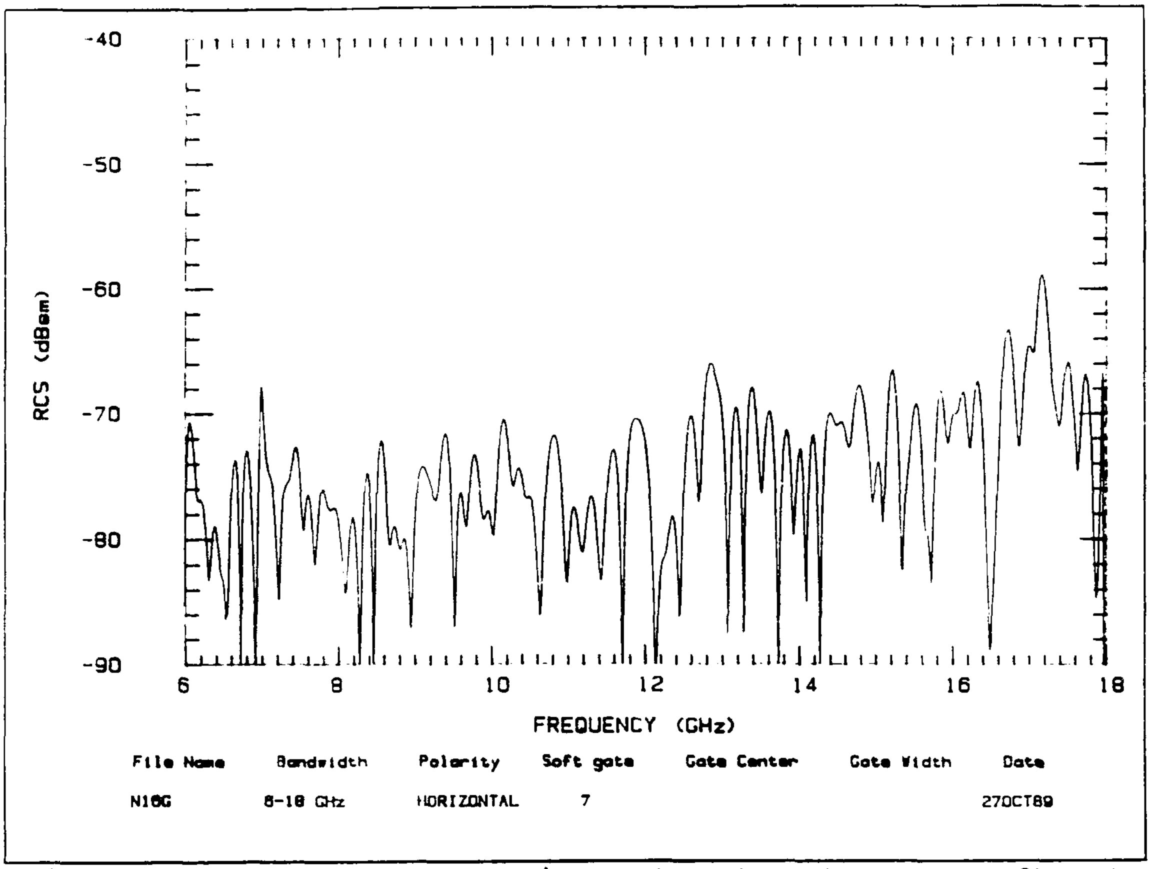
Noise floor of AFIT range using 8-12.4 GHz antennas; soft gate of 7 nsec, averaging factor of 16, and horizontal polarization
Figure 4-2

figure shows the RCS of the empty chamber between 8 to 12.4 GHz, and represents the minimum level of a target return which can be discerned from the returns of the noise sources in the measurement procedure.

Some measurements in this thesis were taken between 6 to 18 GHz, as opposed to 8 to 12.4 GHz, because antennas with a greater bandwidth became available late in the research phase of this study. Preliminary measurements indicate that the new antennas concentrate more energy on the target and thus yield an improved noise floor. Regardless of the antennas used to make the measurements, to obtain results accurate to within ± 0.5 dB, the return from the target should be 10 dB higher than the noise floor. Figure 4-3 shows the noise floor measured using the new, broadband antennas. The noise floor at the WRDC Anechoic Chamber is claimed to be -70 dBsm (7). A brief description of this facility follows.

WRDC Anechoic Chamber ("The Barn")

There are many physical differences between the AFIT chamber and the Barn (a local name for the facility). The primary consideration is how these differences affect the plane wave and free space conditions. The Barn's measurement range is housed in a very large building (shaped like a barn) which allows for a large chamber; approximately twice the size of AFIT's chamber. The measurement facility is a compact range, meaning a parabolic reflector is used to



Noise floor of AFIT range using 6-18 GHz antennas; soft gate is 7 nsec, averaging factor is 16, horizontal polarization
Figure 4-3

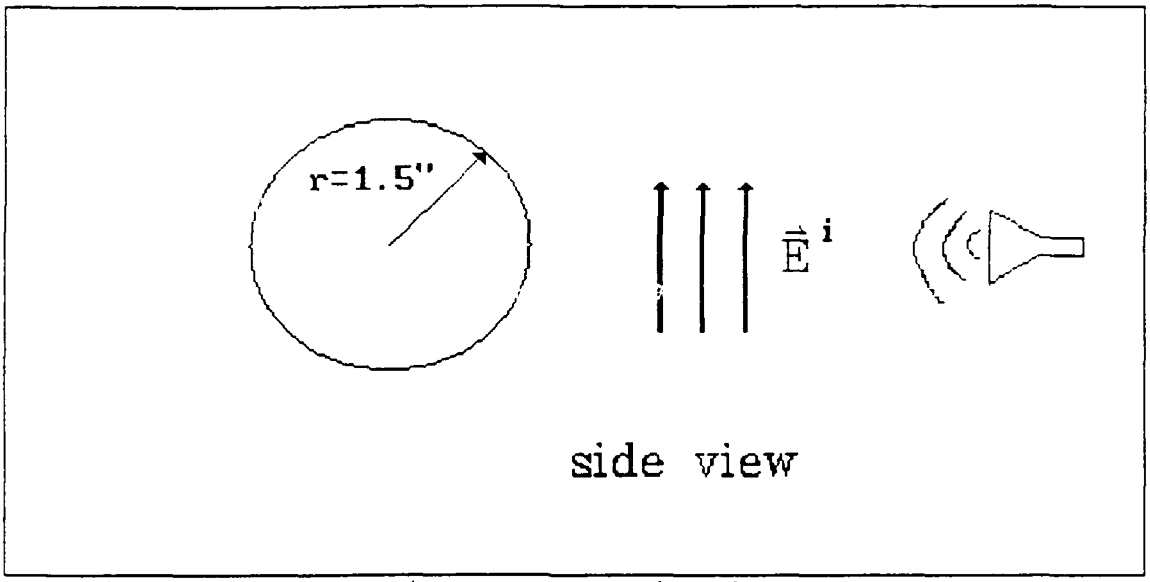
simulate a plane wave. One benefit of the large room and parabolic reflector is a target zone of nearly 10 feet in downrange length. The large room also causes greater spatial attenuation of various error signals, thus improving the free space approximation. The hardware configurations which drive the compact ranges are also different.

The Barn's range is built around a Lintek system instead of the Hewlett Packard Network Analyzer used at AFIT's range. The sources used in each chamber are identical, however the Barn has the capability to simulate a pulsed system by utilizing hardware gates. This is a key factor regarding the free space condition, because only the scattering from objects in the desired downrange location are passed and detected. In addition, only one antenna is required at the Barn which eliminates the cross-coupling energy between antennas which occurs at the AFIT facility. Another difference is the bandwidth of the antennas. The Barn can collect data between 2 to 18 GHz, as opposed to 6 to 18 GHz at AFIT. Some other general comments are the relative easy access to the target pedestal, and the data processing which is independent of the measurement procedure. The above is a fundamental description at best. Questions regarding the capability of the Barn's measurement ranges should be directed to WRDC/SN.

The last notable difference between the two measurement ranges is in the presentation of the product. The scale of the bandlimited impulse response (time domain) is presented in a linear, dimensionless scale as opposed to the dBsm scale used in the AFIT system.

Validation Measurements

The first validation measurement is a frequency response with a vertically polarized incident field on a cylinder of length 12.25 inches and radius 1.5 inches. The cylinder's orientation is shown in Figure 4-4; note that it is broadside to the incident field.



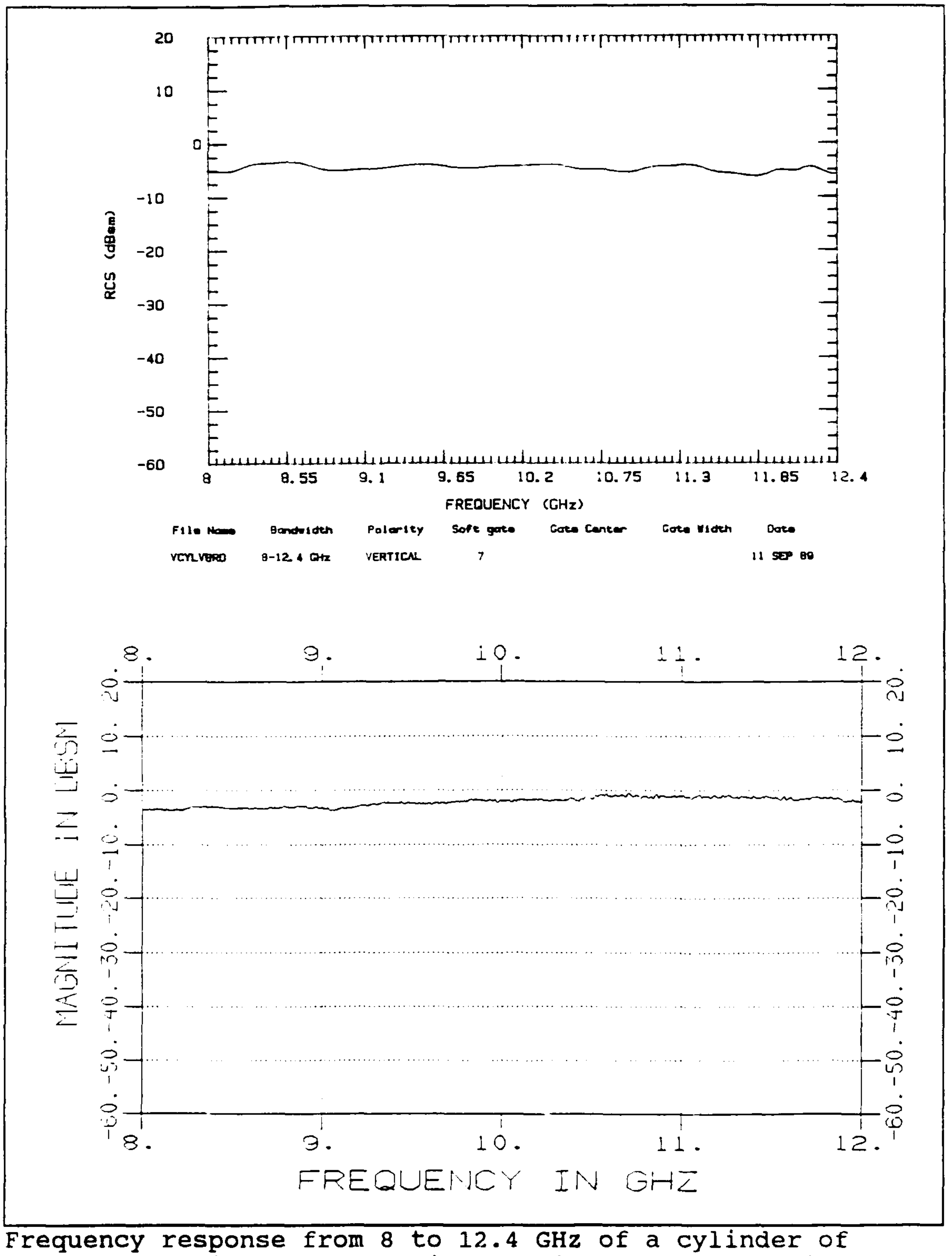
Orientation of cylinder for validation measurements
Figure 4-4

The high frequency approximation for the RCS of a cylinder at broadside is given as,

$$\sigma \approx 2\pi \frac{l^2 a}{\lambda}$$

where a = radius of the cylinder
l = length of the cylinder
λ = wavelength

and predicts a value of approximately -2 dBsm at 8.5 GHz. The frequency responses taken at the AFIT and WRDC measurement ranges are shown in Figure 4-5a and Figure 4-5b, respectively. Both measurements show a slightly lower RCS than the predicted value. The AFIT measurement is slightly lower than the Barn measurement due to a difference in the azimuthal orientation rather than a flaw in the measurement procedure, while the general pattern of the frequency response is very similar for both measurements. In the time domain, the plots are harder to compare because the

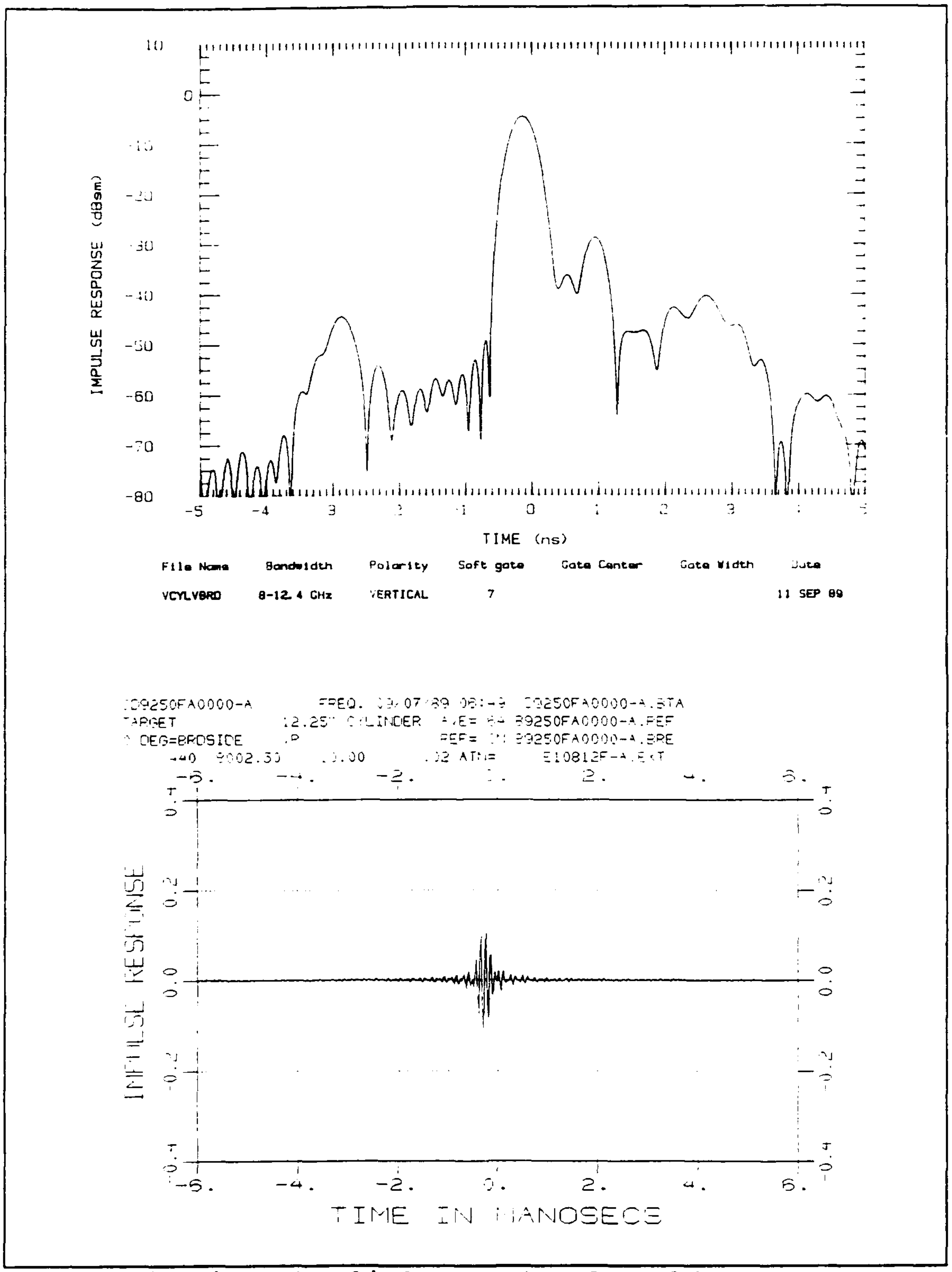


Frequency response from 8 to 12.4 GHz of a cylinder of length 12.25 inches and radius 1.5 inches at broadside and vertical polarization at a) AFIT and b) the Barn
Figure 4-5

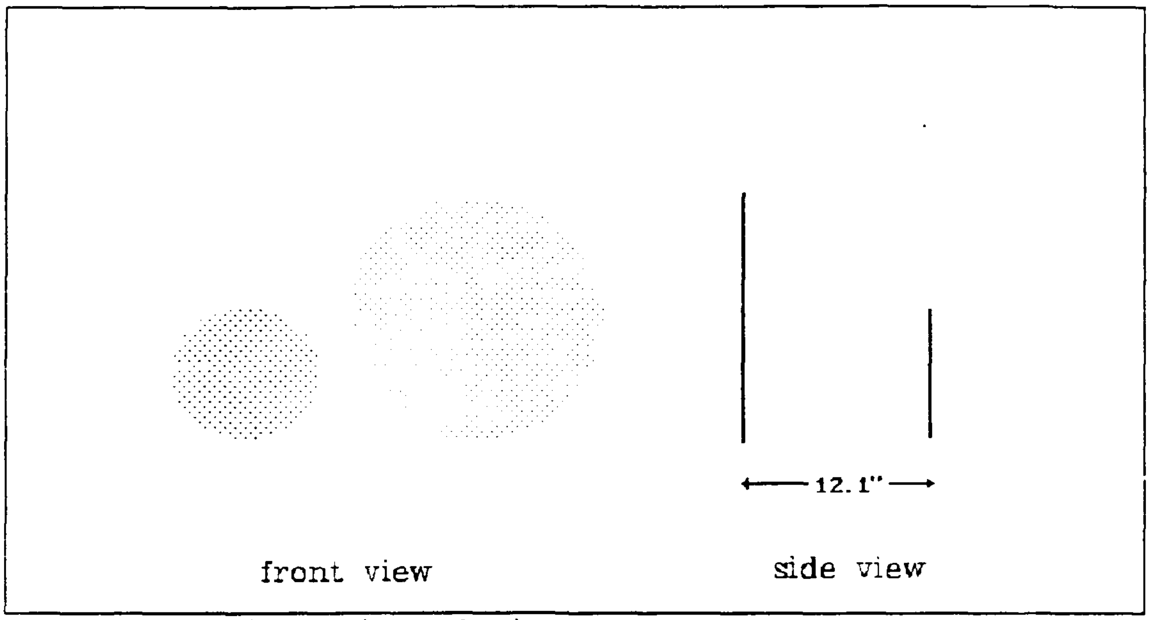
vertical scales are different. The scattering phenomena are plain to see in the AFIT plot (shown in Figure 4-6a), while more difficult to see in the Barn plot (shown in Figure 4-6b). The scattering consists of a reflection and a creeping wave. The longer path length of the creeping wave, referenced to the specular path length, corresponds to a 0.65 nsec roundtrip delay, which is evident in the AFIT plot. The AFIT plot also shows the return due to the double diffraction mechanism which includes the opposite edges. This scattering mechanism has a roundtrip path length corresponding to 1 nsec. In the time domain plot of the Barn's measurement, one is interested in the envlope of the trace (due to their processing). The reflection is evident in Figure 4-6b, while the other mechanisms are not; this is due to the linear scale.

Analysis Technique

The purpose of the next validation measurement is to demonstrate the analytical procedure used in the time domain to isolate seperate scatterers. The target for this measurement is a pair of circular flat plates which are different sizes and separated in the crossrange and downrange directions. The configuration of the plates is shown in Figure 4-7, and the incident field is vertically polarized.

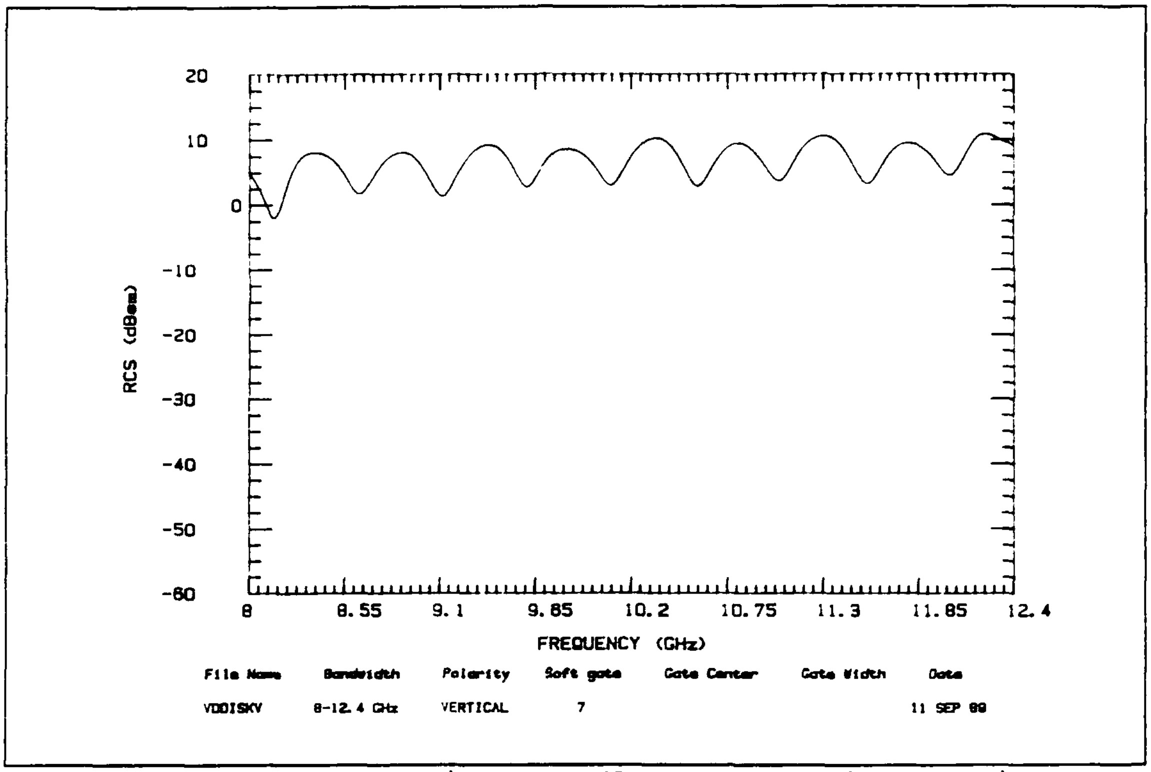


Time domain view of cylinder at a) AFIT and b) the Barn
Figure 4-6



Orientation of circular flat plates for
validation measurements
Figure 4-7

The frequency response provided in Figure 4-8 shows an interference pattern caused by the constructive and destructive phase relationship as the frequency changes. While this information is useful, it is often beneficial to know the frequency response of a single scatterer, or in this example, the frequency response of just one plate. This is accomplished by applying a bandpass filter in the time domain centered over the scatterer of interest. The time domain view of the RCS of the two plates is shown in Figure 4-9. Note that the scattering from each plate is shown by the two peaks, located at -0.71 nsec and 1.34 nsec, and that the temporal separation is the roundtrip time. The temporal path length between these peaks is 2.05 nsec, and indicates the plates are separated by 30.75 cm. Also, the

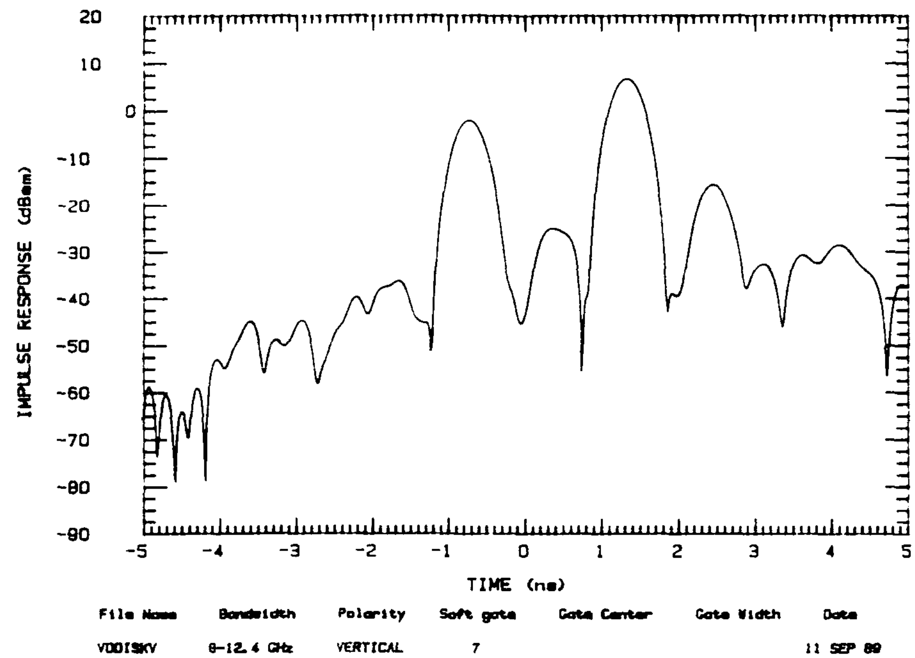


Frequency response of circular flat plates with vertical polarization
Figure 4-8

amplitudes of the returns confirm that the 4 inch plate was in front of the larger 6 inch plate.

A bandpass gate (from -1.36 nsec to -0.06 nsec) is applied around the return from the first plate; the resulting gated time domain is shown in Figure 4-10a. This is then transformed to the frequency domain via a Fast Fourier Transform (FFT). The frequency response of the first plate alone is shown in Figure 4-10b.

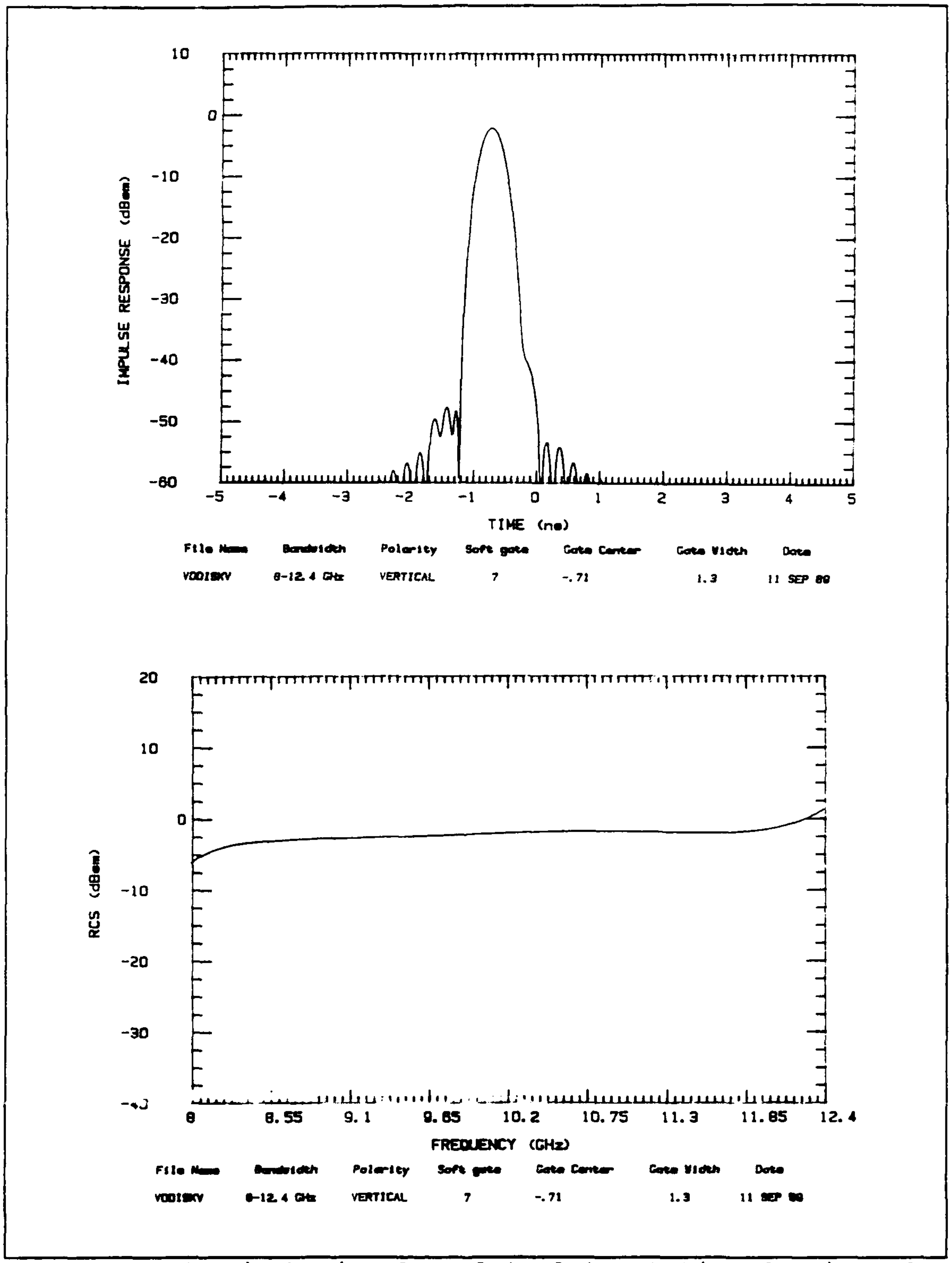
The RCS of a flat plate is dependent on the angle of incidence and wavelength of the incident wave. According to the high frequency prediction formula, $\sigma=4\pi A^2/\lambda$, where A is the area of the plate and λ is the wavelength, the RCS of a



Time domain view of RCS of two plates
Figure 4-9

circular flat plate at normal incidence varies from -2.3 dBsm to 1.5 dBsm as the frequency increases from 8 GHz to 12.4 GHz.

As can be seen from Figure 4-10b, the effects of the processing are evident at the edges of the bandwidth, near 8 GHz and 12.4 GHz. When these effects are excluded, the frequency response exhibits the proper trend regarding the frequency dependence, namely, the RCS of a flat plate increases as the frequency is increased at normal incidence.



Gated RCS of 4 inch circular flat plate a) time domain and b) frequency response
Figure 4-10

Measurement Results

The improvements and new capabilities of the AFIT far-field measurement range have been fully described and verified. The next phase of the research is to use the facility to investigate the effect of a metallic versus a transparent canopy on the total RCS of an aircraft. The approach for the investigation is based upon measurements of scale model aircraft and measurements of a test body specifically designed to isolate the cockpit/canopy area.

The organization of this chapter mirrors the major chronological events of the research. The foundation of the measurement process was a sufficiently bounded measurement test matrix which would ensure appropriate data to accomplish the identified objective of the research. The next task was the judicious selection of a scale model aircraft which would maximize the benefits for the intended research, but not violate the physical limits of the chamber. Measurements of the scale models were then taken in three configurations (specified later in this chapter) to determine the relative magnitude of the scattering of the canopy and cockpit with respect to the scattering from the entire aircraft. The measurement results for the scale model aircraft were then analyzed and the conclusions documented. The next logical step to investigate the scattering from the subject area was to isolate the cockpit/canopy from the aircraft. To achieve this, a test body was designed, again, with the chamber limitations in mind. After the measurement of the test body, the final task was to analyze the data and draw conclusions from the results.

Measurement Matrix

The objective of the measurements is to investigate the scattering from the cockpit/canopy area relative to the scattering from the entire aircraft. The following paragraphs discuss the measurement conditions which were either required by the ARMS measurement procedure and/or appropriate for the research.

A thorough investigation of the angular dependence of the scattering is outside the scope of the study, therefore all frequency response measurements were nose-on and at a zero degree elevation angle. All measurements were taken with both a vertically and horizontally polarized incident field. The frequency dependence of the scattering was within the scope of this study, however, the availability of the transmit and receive antennas determined the frequency range with which the targets could be measured. Frequency responses of the scale model aircraft performed at the AFIT range were only measured between 8 and 12.4 GHz, while similar measurements taken at the Barn of any target could be in any bandwidth between 2 and 18 GHz. Frequency responses of the test body were taken from 6 to 18 GHz at both facilities, because wider bandwidth antennas became available for use at the AFIT chamber for these measurements. The illuminating frequencies for pattern cuts were 8 GHz and 10 GHz.

Two target configurations were used to simulate a perfectly metallic and a perfectly transparent canopy. The metallic canopy was modeled by painting the canopy with the same metallic paint used to cover the target such that the cockpit of the target was completely shadowed from the incident field. The transparent canopy was modeled by simply removing the canopy from the target. In this configuration, the cockpit was totally illuminated. The measurement conditions are summarized in the test matrix shown in Figure 5-1.

Scale Model Selection

The first step in selecting a scale model aircraft was to define the requirements which would fully describe the perfect target to be measured. The next step was to conduct a tradeoff between the perfect target and the practical considerations of readily available but less-than-perfect targets.

The two main criteria in selecting the scale model aircraft were the size and type. The type of aircraft was selected from modern fighters, because their requirement for situational awareness is typically satisfied via an exposed, bubble-shaped canopy. The F-16A and F-15E fighters were then chosen. The size of the fighter model is clearly

hamber	Type Meas	Pol	Freq (GHz)	F-18 CAN	F-18 SET	F-18 COC	F-15 CAN	F-15 SET	F-15 COC	TEST BODY CAN	TEST BODY COC
AFIT	FREQ RESP	VERT	8-12.4	x	x	x	x	x	x		
			6-18							x	x
		HORIZ	8-12.4	x	x	x	x	x	x		
			6-18							x	x
	PATTERN CUT	VERT	8								
			18	x	x	x	x	x	x		
		HORIZ	8	x	x	x					
			18	x	x	x	x	x	x		
BARN	FREQ RESP	VERT	8-12.4	x	x	x	x	x	x		
			6-18	x		x	x		x	x	x
			2-18	x	x	x	x	x	x	x	x
		HORIZ	8-12.4								
			6-18	x		x	x		x	x	x
			2-18	x		x	x		x	x	x
	PATTERN CUT	VERT	8	x		x	x		x		
			18	x		x	x		x		
		HORIZ	8								
			18								

Measurement test matrix
Figure 5-1

limited by the dimensions of the target zone of the chamber. The target zone was defined in chapter II as the area in the measurement chamber in which the incident wave approximated a plane wave within designated phase and amplitude variation standards. The target zone of the AFIT range is centered on the target pedestal, and is cylindrically shaped with a length of 3.2 feet and a diameter of eight inches. In the case of the fighters, the wing span was the limiting factor.

The largest scale model which could properly occupy the target zone was calculated to be approximately 1/46 of the full size of the target. The 1/46 scale model was deemed insufficient to achieve the desired objective because of the following reasons: the length of the cockpit/canopy on this size was only 2.75 inches, a model of this particular scale was not commonly available, and the range resolution for a frequency response between 8 to 12.4 GHz was 2.6 inches. Based on the above reasons, it was decided to measure a 1/32 scale model of the F-16A and F-15E fighter aircraft.

The scaled targets were built from plastic model kits, and assembled in an airborne configuration without any external stores or weapons. The cockpit of the aircraft contained a removable seat and the normal features found in a plastic model kit, including the Heads-Up Display (HUD). If necessary, the kit was modified so the canopy/fuselage interface was smooth, and the canopy was easily removable from the fuselage. Finally, all surfaces of each fighter, including the cockpit, were painted with metallic copper paint so that the targets were highly conductive. The test for conductivity was a resistance of less than 3 ohms between any two points on the target.

Before showing the measurement results of the scale model fighters, the following paragraphs briefly describe the measurement procedure and decode the abbreviated titles of the plots. Although the conditions of each measurement are documented in the writing, the explanation is intended to aid the reader in examining the data.

The ARMS code requires one array to be filled for each of the following: reference target, reference target background, target, and target background. (Recall the option to skip the target background measurement if the target background is identical to the reference target background.) For the scale model measurements, the reference target background and the target background was a six inch styrophoam column, so the above-mentioned option was used. The option was very important because it allowed the target configuration to be changed without moving the entire aircraft. For example, a measurement run is the consecutive measurement of the three target configurations (without re-measuring the target background) by altering, but not moving, the model in the following manner. First, the model was measured with the canopy, then the canopy carefully removed (yielding the cockpit with a seat), and finally, the seat removed. All measurements were taken with a RAM cap over the target pedestal.

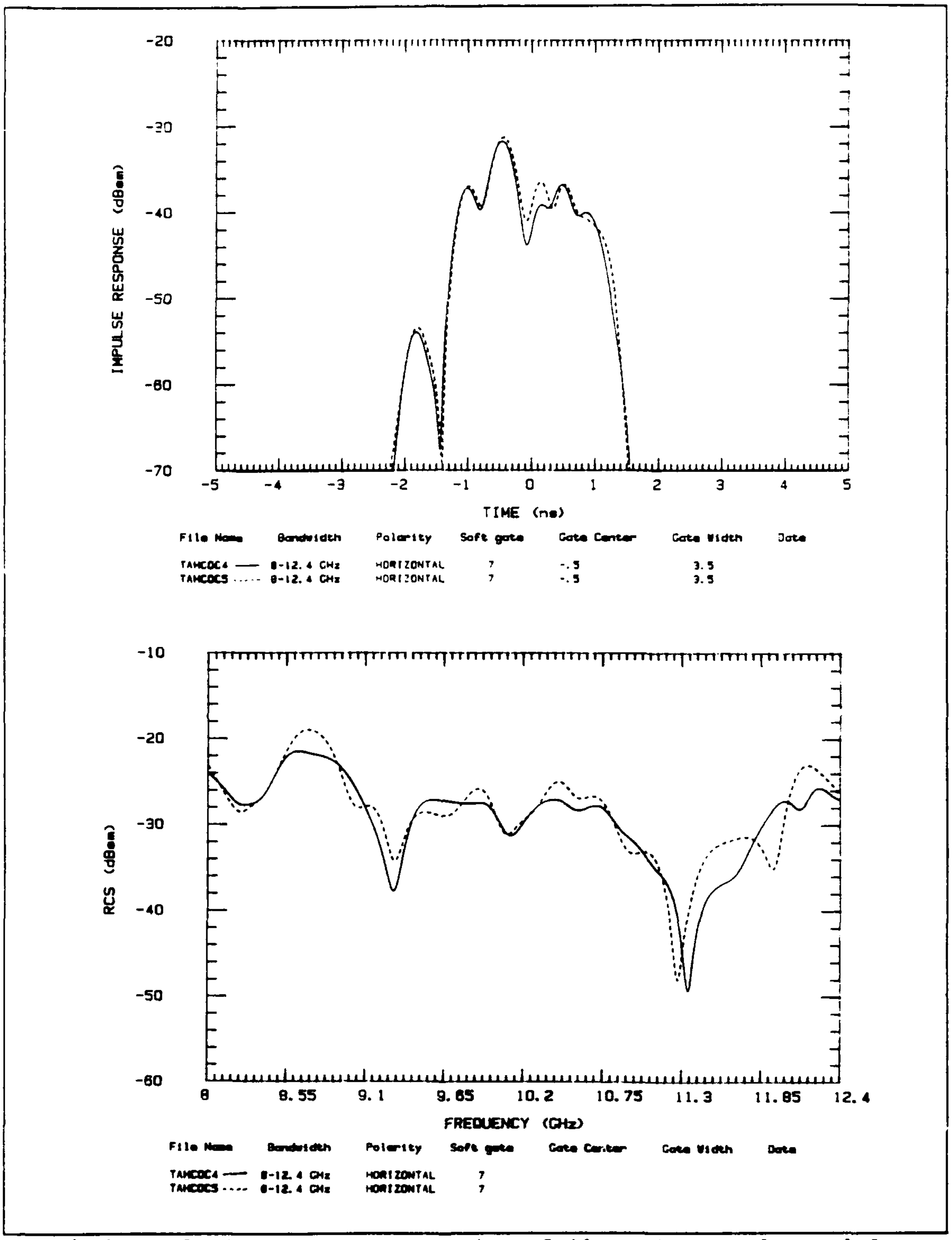
Due to the limited space available for labeling the plots, the filename is encoded. The first two letters designate the target; the third letter designates the polarization of the incident field; the fourth, fifth, and sixth letters represent the target configuration; and the seventh and eighth letters designate the measurement set number. The targets are coded as follows: TA (1/32 scale model F-16), TB (1/32 scale model F-15), and TC (test body).

The target configuration codes are: CAN (aircraft with canopy on), SET (canopy off; cockpit with seat), and COC (cockpit without seat). For example, the filename TAVCAN2B is a measurement of target TA (the 1/32 scale model F-16) with a Vertically polarized incident field and the CANopy on.

Measurement Results

Although the performance and accuracy of the AFIT range was demonstrated with validation measurements, some questions were raised concerning the performance of the system when the target was a complex, low level scatterer, such as a small model aircraft. In particular, a significant concern was the consistency of the results, and the repeatability of the measurement procedure.

An extensive number of frequency response measurement runs were performed to resolve this concern, and all target configurations produced the same conclusions. Figure 5-2 shows the RCS for two independent measurements of the F-16 without the canopy or seat in the time domain and frequency domain. The incident field is horizontally polarized. The frequency domain plot shows the general patterns are very similar, as the RCS is within 2.5 dB except where the nulls are slightly shifted at 11.3 GHz. This amount is representative of the error associated with the placement and mounting of the target.

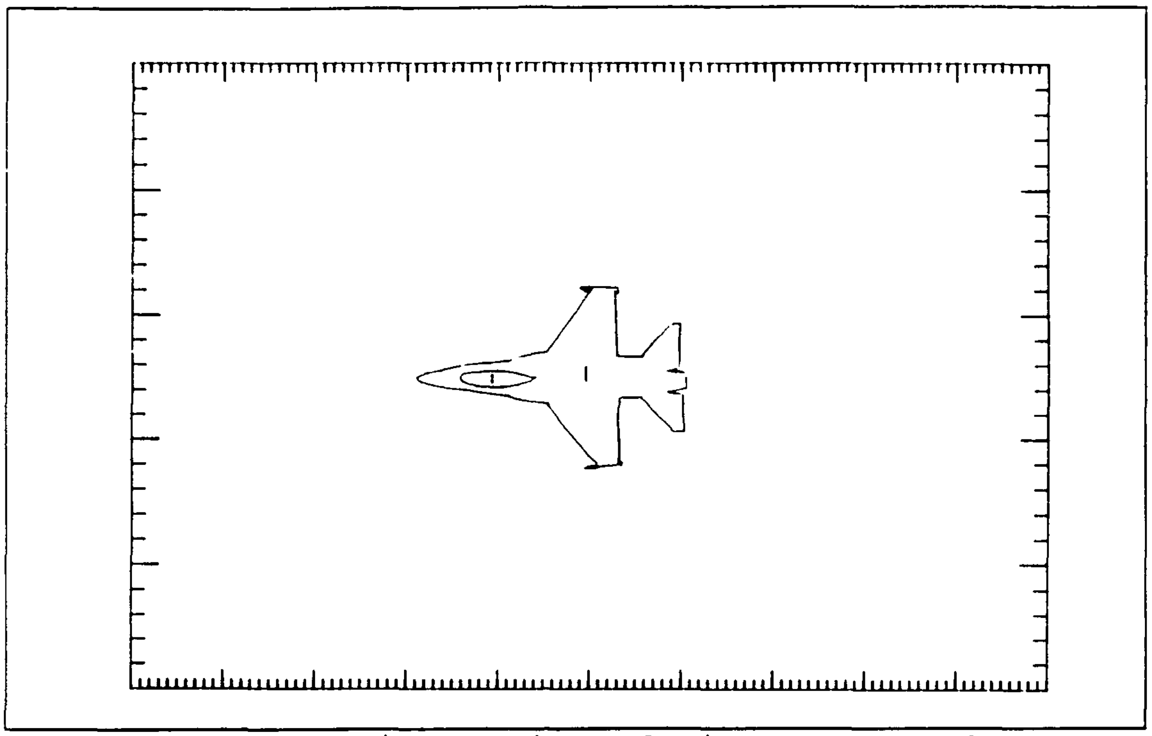


Two independent RCS measurements of the 1/32 scale model F-16; cockpit without seat, horizontal polarization; a) time domain and b) frequency response

Figure 5-2

The data in the time domain also shows the repeatability of the measurement procedure. As can be seen from Figure 5-2a, however, the traces begin to diverge as the number and complexity of the scatterers which compose the return increases. For example, the traces are almost identical up to 0 nsec, which corresponds to approximately 65 percent of the length of the model. Towards the rear of the target, the number of scatterers increases which results in minor deviations between the traces. The canopy/cockpit area, incidentally, is well within the forward half of the model F-16. The dominant scatterers on the target are always in close alignment, even beyond 0 nsec, as can be seen at 0.5 nsec on Figure 5-2a. Target alignment is chiefly responsible for the minor differences in the time domain traces.

The next logical step is to identify the scatterers which are evident in the time domain plot of the RCS. To aid in the analysis, a template of the target is overlayed on the time domain plot of the target's RCS. The template is, of course, scaled and positioned to correspond to the target's actual downrange position in the chamber. A time gate from -2.0 to 1.0 nanoseconds is applied to the F-16 data to eliminate the returns not caused by the target. The template, shown in Figure 5-3, indicates the scattering from the nose of the F-16 occurs at -1.85 nsec with respect to the center of the reference target, and similarly,



Template for time domain analysis of 1/32 scale F-16
Figure 5-3

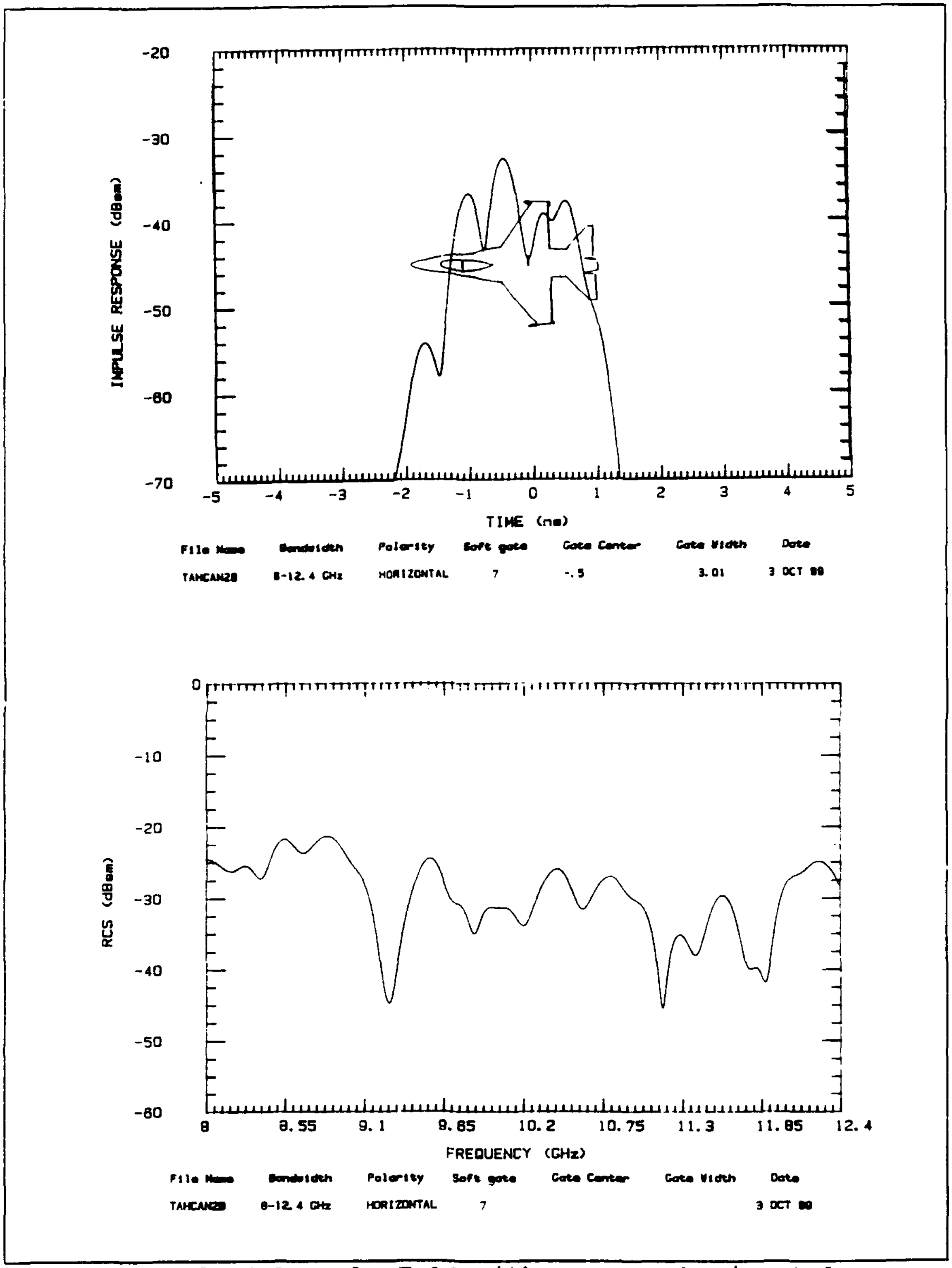
scattering from the tail of the F-16 corresponds to 1.05 nsec from the center of the reference target.

F-16, 8 to 12.4 GHz, horizontal polarization, AFIT. The first target to be analyzed is the 1/32 scale F-16 (TA) with a horizontally polarized incident field. The next three figures (Figures 5-4 through 5-6) show the RCS for each of the three target configurations in the time domain and frequency domain. The following paragraphs refer to the time domain plots for each target configuration.

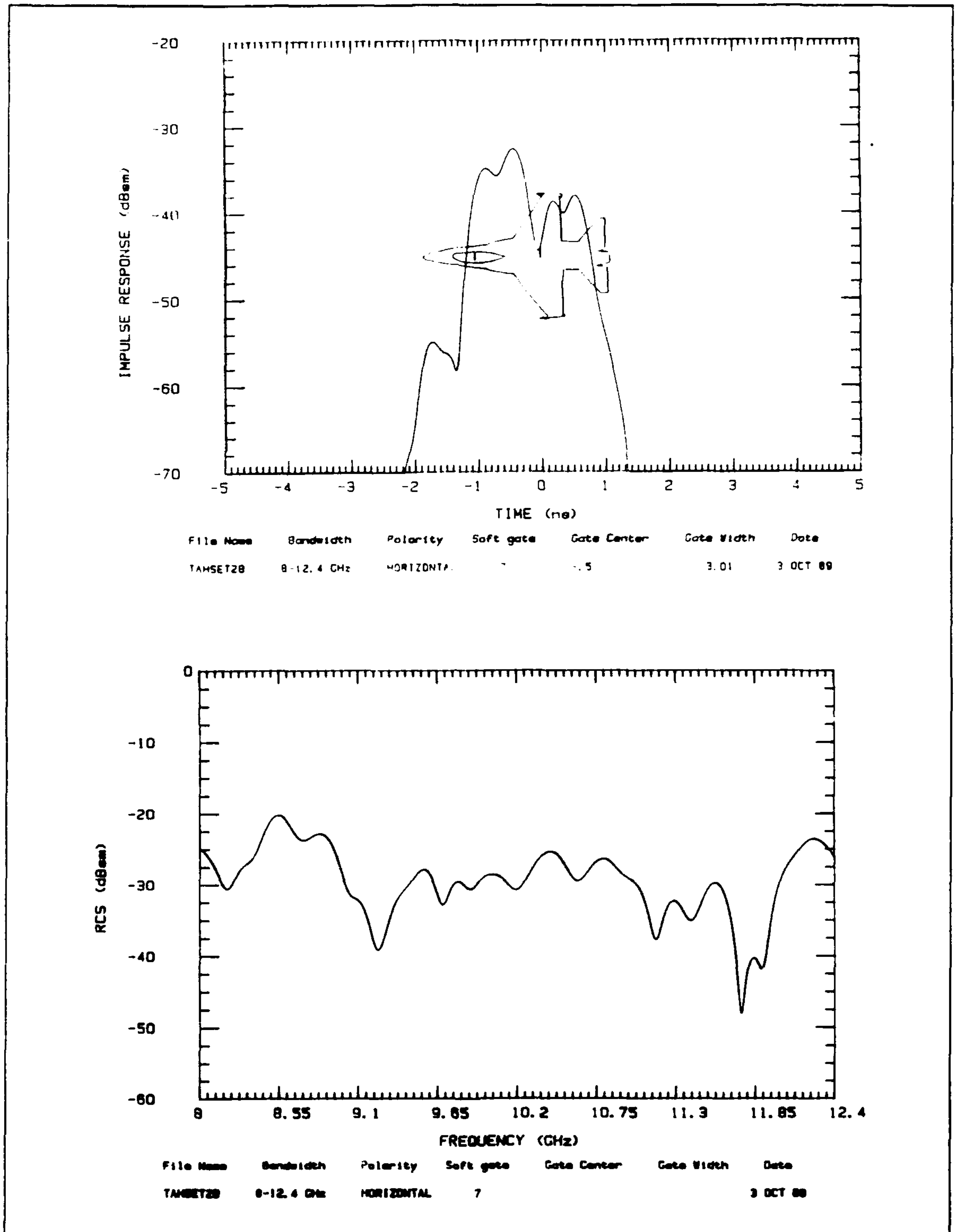
The first scatterer in all three measurements is unmistakenly due to the nose of the target. The -55 dBsm level of the return is comparable to the RCS of a similarly dimensioned cone, and the time of the return, -1.75 nsec, closely corresponds to the downrange location of the nose.

The next resolvable return for each configuration is close in temporal location but different in magnitude. The return does not occur at the calculated location of the front of the canopy, -1.3 nsec, as one might expect. Instead, the return, occuring at -1.0 nsec for the CAN configuration, -0.97 nanoseconds for the COC configuration, and -0.9 nsec for the SET configuration, is most likely due to the engine inlet which is located directly beneath the center of the canopy. Because the range resolution for a frequency response from 8 GHz to 12.4 GHz is only 2.6 inches (see page 36), the temporal differences in the target configurations cannot be resolved from the dominant scattering of the engine inlet. The result is that the subject return for each configuration is slightly skewed about the temporal location of the scattering from the engine inlet. The magnitude of the returns are the only distinguishing feature of the three target configurations.

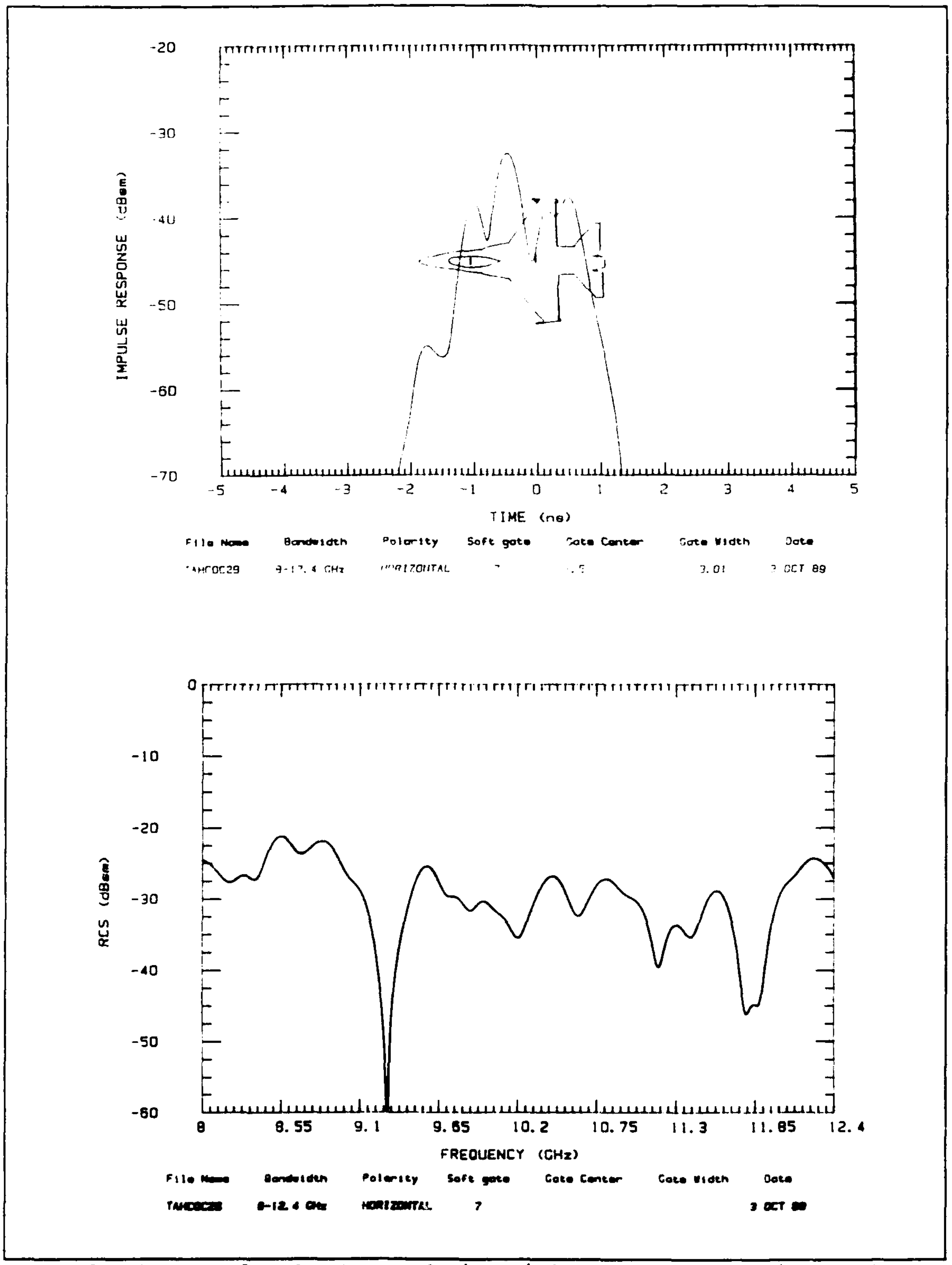
The configuration which caused the highest return, not surprisingly, was SET (the cockpit with the seat), because the seat was directly illuminated by the incident field. A notable observation, however, is that the canopy caused a larger return than the empty cockpit. The RCS at roughly the center of the canopy for the SET, CAN, and COC



RCS of 1/32 scale F-16 with canopy, horizontal polarization; a) time domain and b) frequency response
Figure 5-4



RCS of 1/32 scale F-16, cockpit with seat, horizontal polarization; a) time domain and b) frequency response
Figure 5-5



RCS of 1/32 scale F-16, cockpit without seat, horizontal polarization; a) time domain and b) frequency response
Figure 5-6

configurations are -35 dBsm, -37 dBsm, and -39 dBsm, respectively. The trend of the magnitude of the returns for the three configurations was not discernible from the frequency response plots.

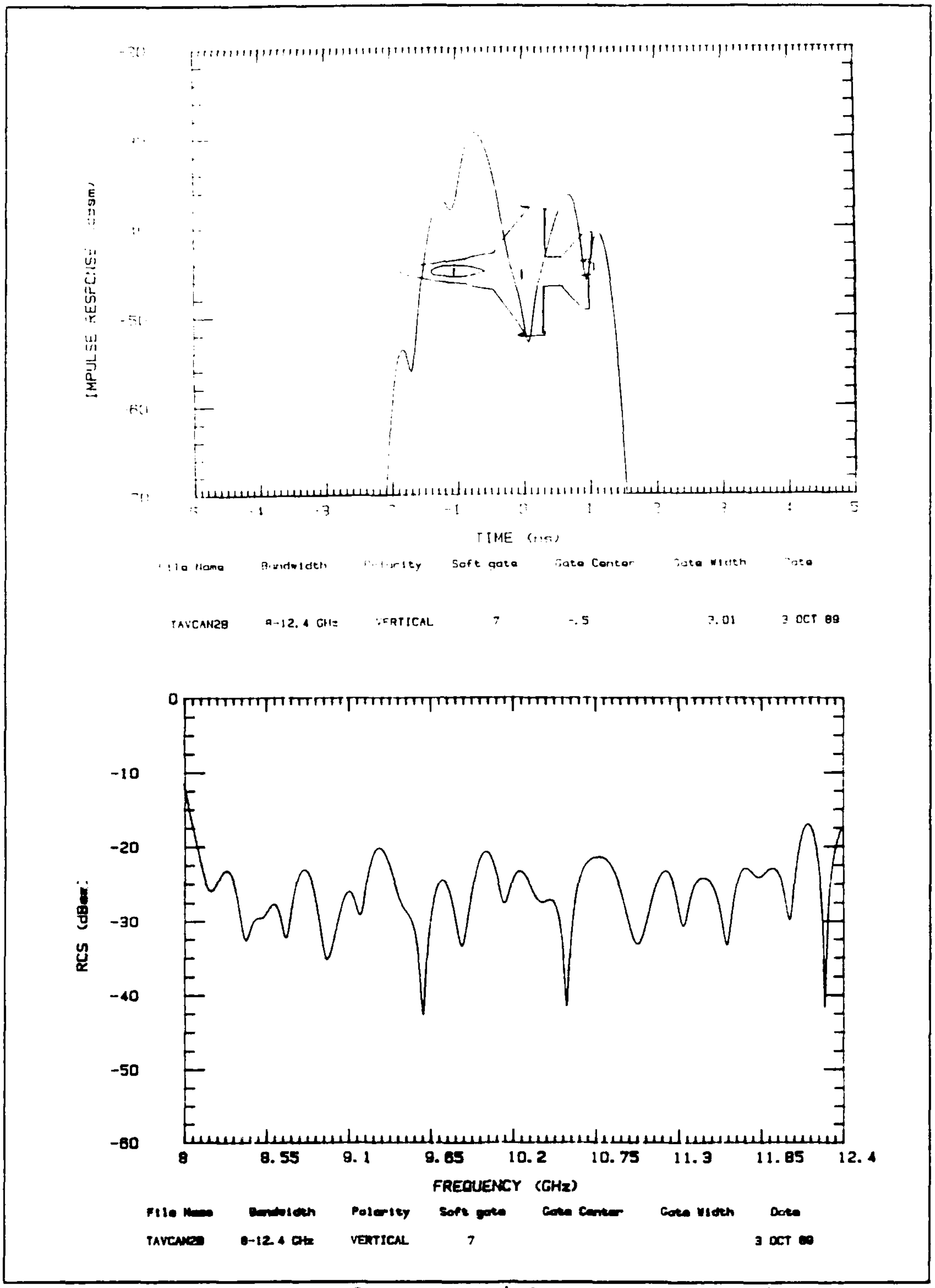
The final return of interest occurs at -0.45 nanosec with a magnitude of -32.5 dBsm. This return is independent of the target configuration and is believe to be a result of the scattering from the end of the engine inlet cavity.

In summary, for a horizontally polarized incident field, little information regarding the scattering from the canopy/cockpit area of the F-16 model was gained. This is primarily because the electric field was aligned with and scattered from the horizontally oriented and oblong-shaped engine inlet, thus obscuring the electromagnetic view of the subject area. Also, the range resolution of the AFIT chamber was inadequate to separate the scatterers in the different target configurations. It was confirmed, however, that the cockpit with the seat is a dominant scatterer, while it was learned that the canopy scattered more (2 dB) than the empty cockpit. Although little was learned about the scattering from the canopy/cockpit, the conclusion is useful information in the context of the entire model aircraft.

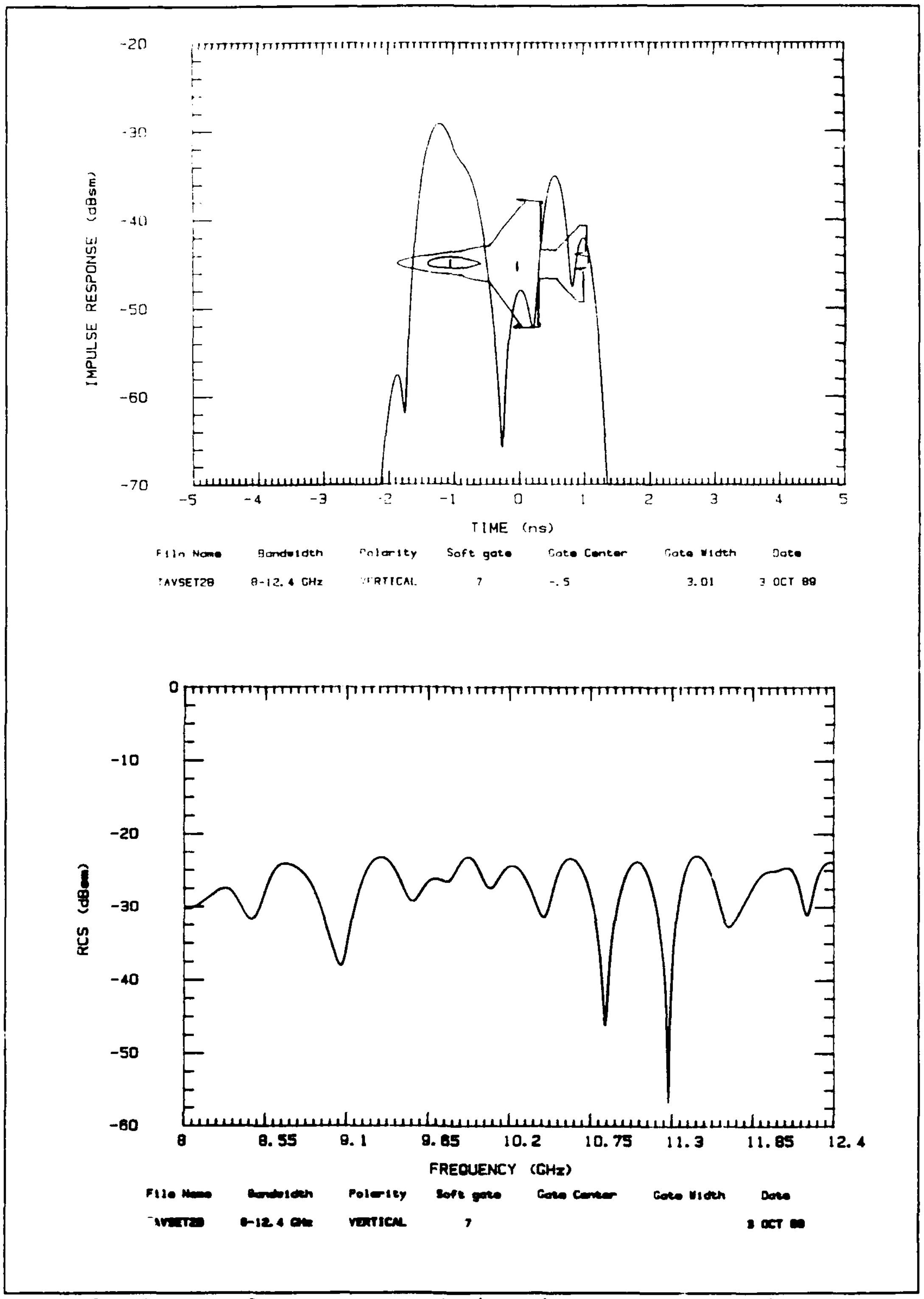
The next task was to perform an identical set of measurement runs at the AFIT far-field measurement range to investigate the scattering from the subject area with a vertically polarized incident field. In the same format as with the preceding horizontally polarized measurements, the data is provided in a series of six plots (Figure 5-7 through 5-9). As before, the nose of the aircraft is the first resolvable scatterer based on the temporal location and magnitude of the response. The level is almost 4 dB lower than the same measurement with a horizontally polarized field. The difference is caused by the asymmetry in the nose of the aircraft.

An interesting observation is that the discontinuity caused by the intersection of the fuselage and the front of the canopy is now apparent. The peaks which occur at approximately -1.3 nanoseconds in all three configurations correspond to this point. As in the previous case, the seat configuration is the dominant scatter, but the empty cockpit now scatters more than the canopy by at least 6 dB, as one might expect. Figure 5-10 shows the time domain returns for the three target configurations on one plot.

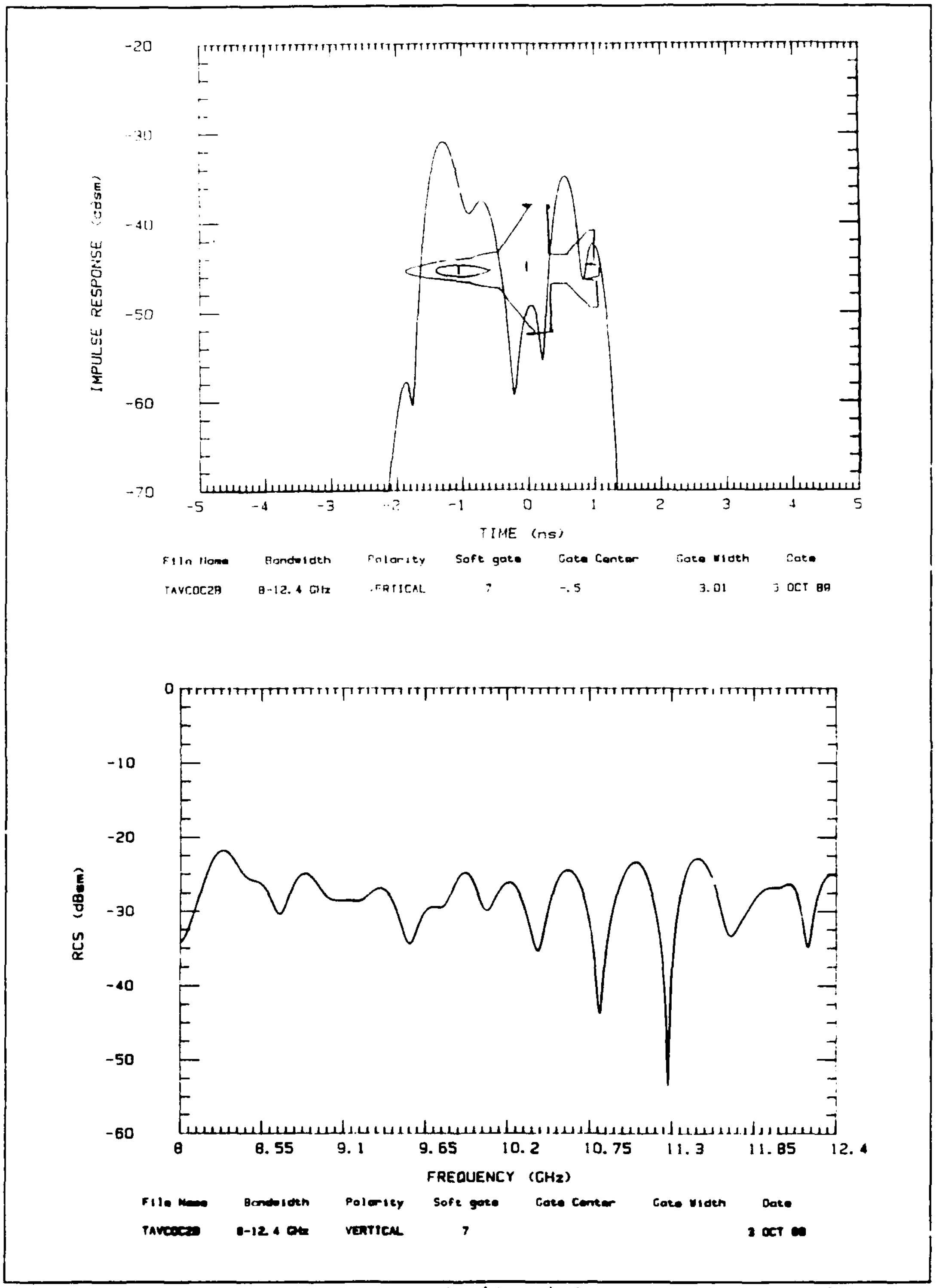
Another unexpected result occurs at -0.7 nsec which corresponds to the discontinuity caused by the intersection between the back of the canopy and the fuselage. Significant scattering occurs with the canopy, possibly via a traveling wave propagating from the front of the canopy to the back. Also, the scattering from the end of the engine inlet cavity, which was so dominant with the horizontally polarized field, is not present.



RCS of 1/32 scale F-16 with canopy, vertical polarization; a) time domain and b) frequency response
Figure 5-7

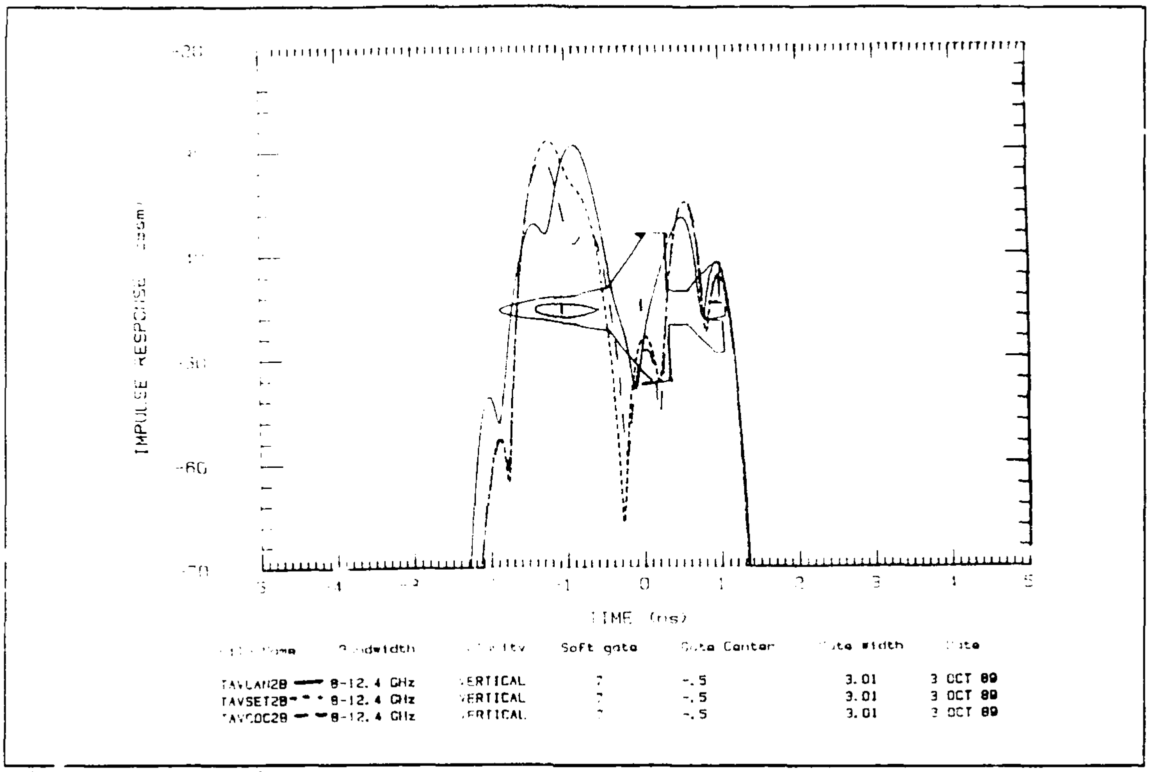


RCS of 1/32 scale F-16, cockpit with seat, vertical polarization; a) time domain and b) frequency response
Figure 5-8



RCS of 1/32 scale F-16, cockpit without seat, vertical polarization; a) time domain and b) frequency response

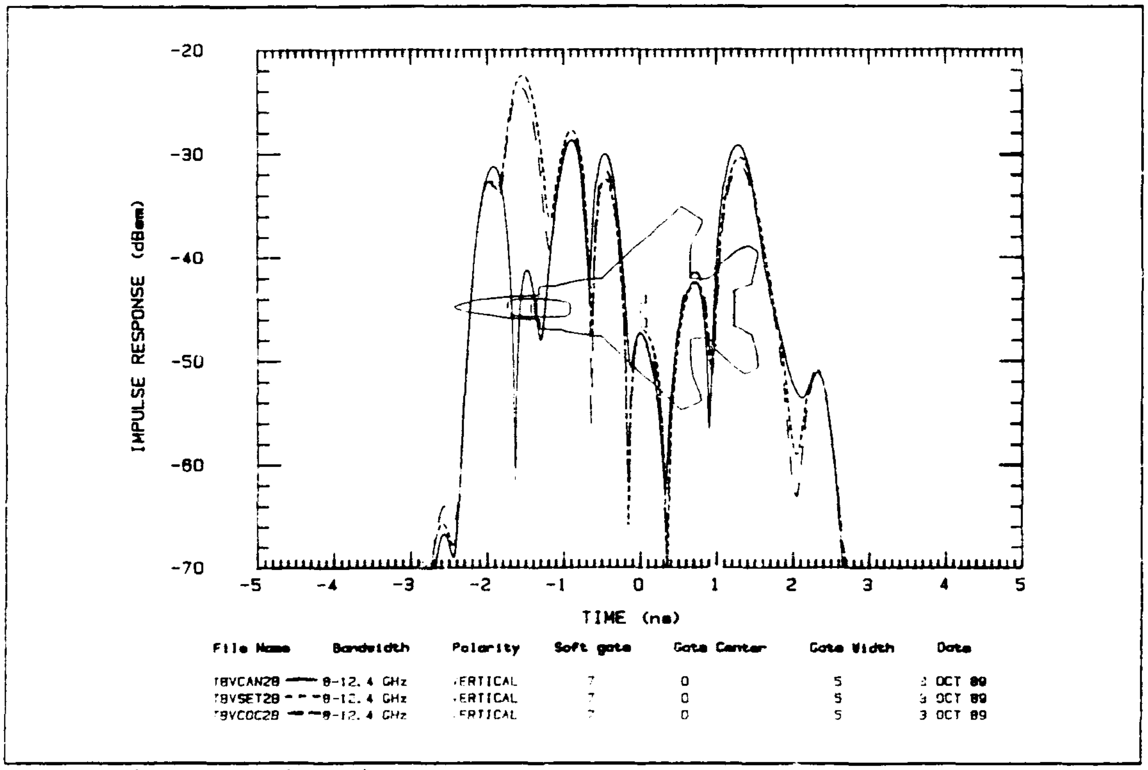
Figure 5-9



Time domain view of RCS of 1/32 scale F-16, three target configurations, vertical polarization
Figure 5-10

The effect of the polarization of the incident field is significant and beneficial to the objective of this thesis. The benefit is two-fold. Not only is the scattering from the canopy/cockpit area more apparent, but the undesirable scatterers on the model, such as the engine inlet and cavity, appear to scatter less. The measurement runs of the other targets in this effort are only analyzed for the case of a vertically polarized incident field based on the merits of thi conclusion.

One solution to the problems associated with measuring the relatively small scale model aircraft at the AFIT range was to measure an aircraft with a larger canopy/cockpit, such as the F-15E. The results and conclusions, however, were very similar to those for the F-16, with one exception. The difference in the magnitude of the scattering between either cockpit configuration and the scattering from the canopy configuration at the temporal location of the seat was significantly higher than the same location on the F-16. Nearly a 20 dB difference is very clear in the time domain plot shown in Figure 5-11.



Time domain view of RCS of 1/32 scale F-15, three target configurations, vertical polarization
Figure 5-11

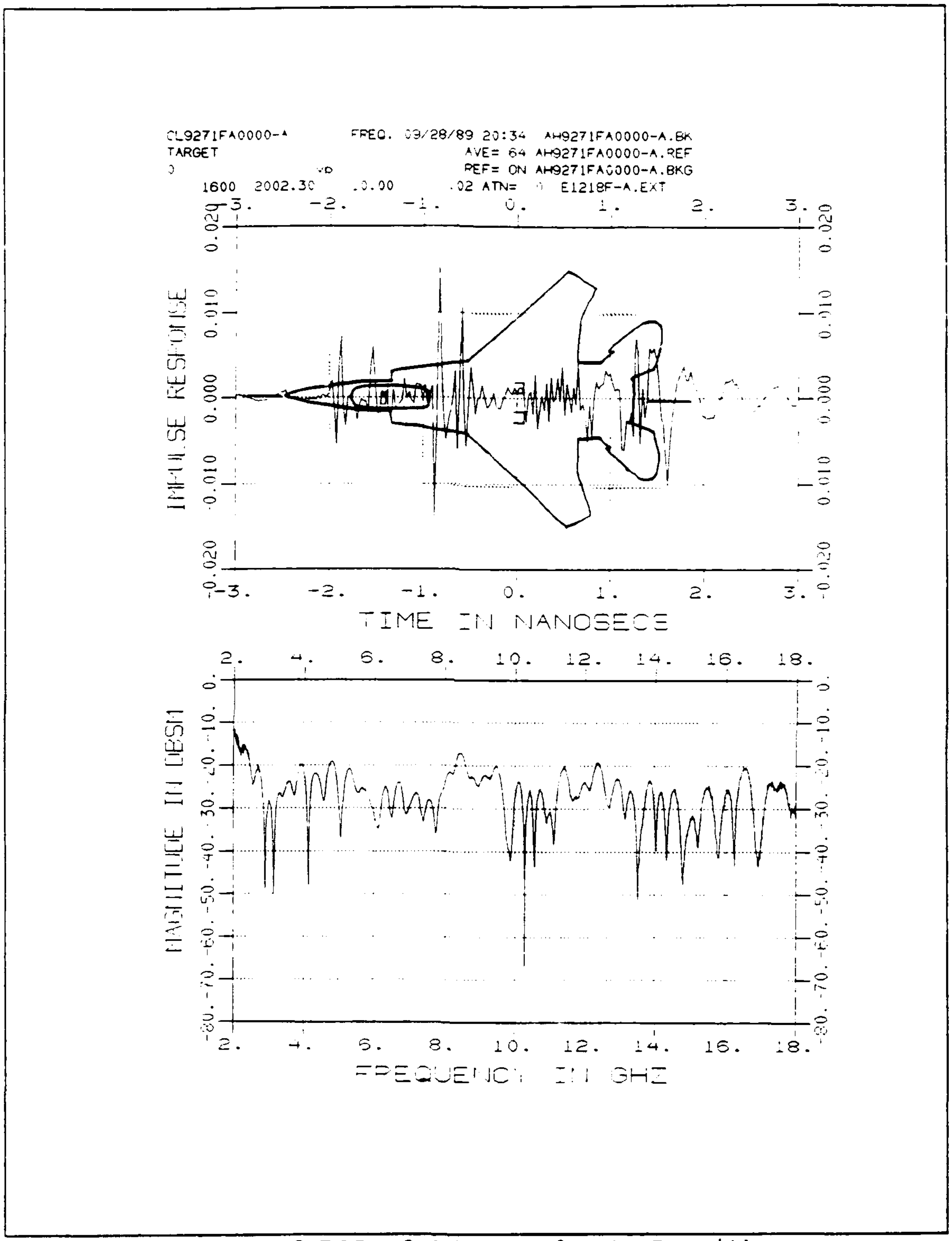
To further investigate the scattering of the canopy/cockpit area, the 1/32 scale F-16 and F-15 models were measured at the Barn, which is capable of a broader frequency coverage and better time domain resolution. Given the information obtained thus far, the scenario measured at the Barn was selected to produce the best opportunity to observe scattering from the subject area. Based on the lessons learned from the scale model measurements taken at the AFIT chamber, it was decided to concentrate on measurements of the F-15 from 2 GHz to 18 GHz with a vertically polarized incident field. (Measurements were also taken from 8 GHz to 12.4 GHz for validation purposes; these yielded the same results obtained at AFIT).

F-15, 2 to 18 GHz, vertical polarization, the Barn. As before, the three target configurations were measured, and the time domain and frequency response plots for each configuration are provided in Figure 5-12 through Figure 5-14. A template of the model is overlayed on selected plots to aid in viewing the data.

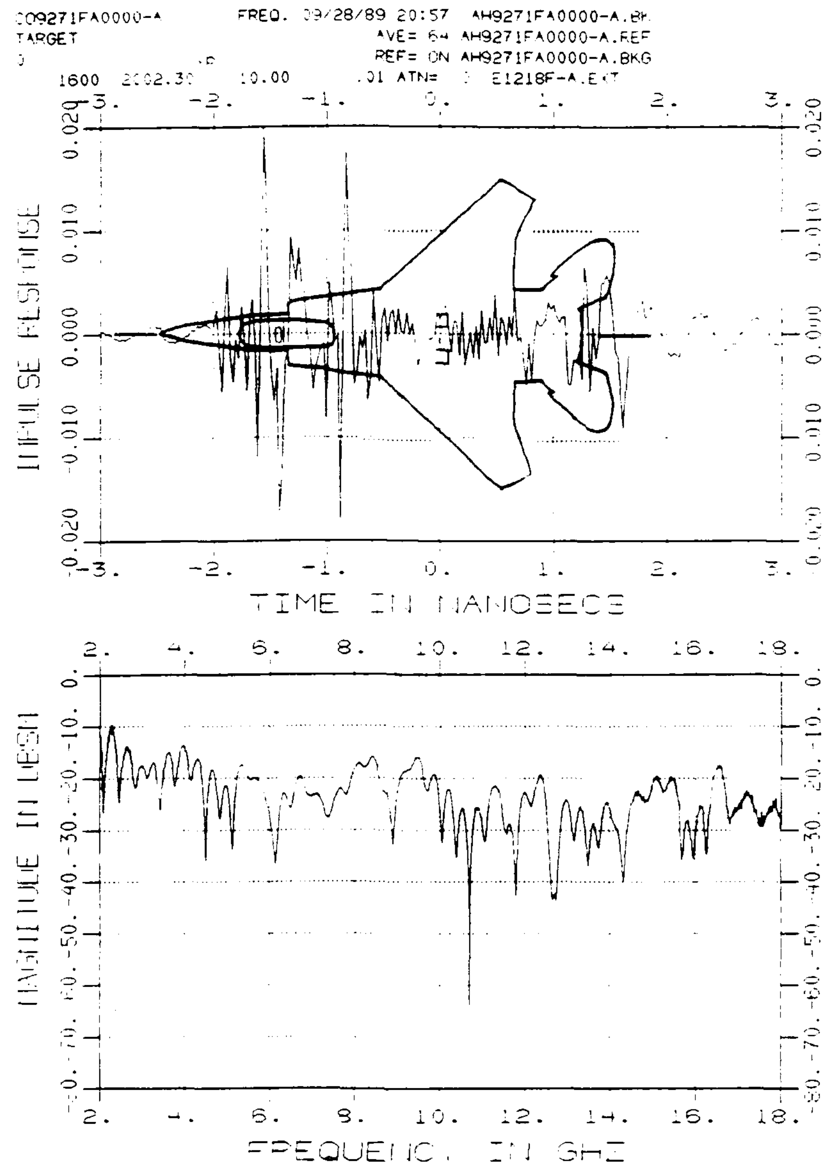
The general conclusions are the same as those drawn from the AFIT measurements; the SET configuration yields the strongest scattering, followed by the COC and CAN configurations, respectively, The difference, however, is that the range resolution of the Barn facility provides more detailed information on which to base and defend the conclusions. Recall that the AFIT time domain measurement of the F-15 (Figure 5-11) yielded only one peak which distinguished the three target configurations. As can be seen from the time domain plots, there are many scatterers which contribute to the overall return and can be isolated for further analysis.

The first task is to identify the causes of the major peaks which occur in the region of interest. The front and back of the cockpit define this region, which extends from -1.8 nsec to -0.9 nsec, respectively. By observing the effect that changing the target configuration has on the amplitude of a peak, and knowing the temporal location which corresponds to the physical position of suspect scatterers, the significant contributors can be identified. For a complex target such as an aircraft, care must be exercised. A radar return could be the result of multiple reflections, resulting in a time domain peak that does not correspond to the downrange position of a specific scatterer.

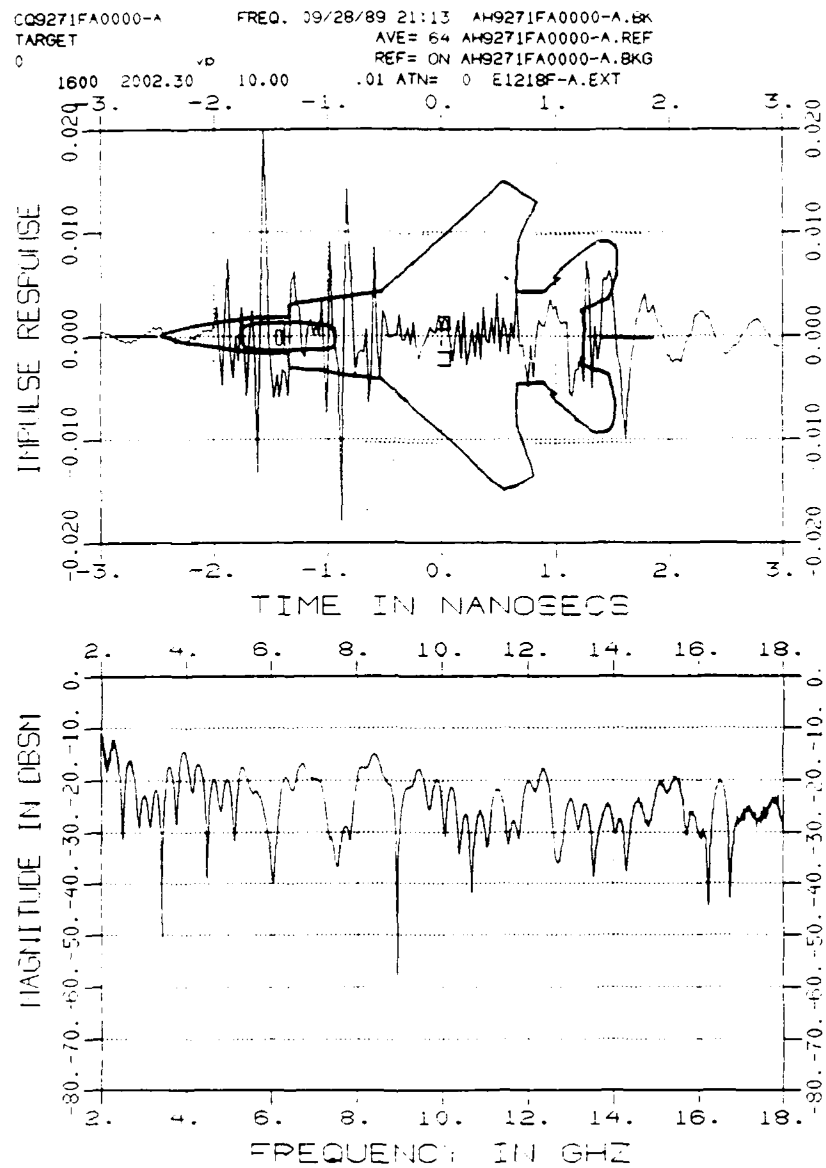
There are five scatterers which produce significant returns in the region of interest. The first scatterer is the discontinuity formed by the front of the canopy. The return from this scatterer is identical for the SET and COC configurations, but is significantly reduced in the CAN configuration. The next two scatterers share the same downrange distance which corresponds to -1.6 nanoseconds. The first of these occurs in the CAN configuration and is due to the discontinuity caused by the junction between the



Barn measurement of RCS of 1/32 scale F-15, with canopy, vertical polarization; a) time domain and b) frequency response
Figure 5-12



Barn measurement of RCS of 1/32 scale F-15, cockpit with seat, vertical polarization; a) time domain and b) frequency response
Figure 5-13



Barn measurement of RCS of 1/32 scale F-15, cockpit without seat, vertical polarization; a) time domain and b) frequency response

Figure 5-14

two pieces which compose the canopy. The other scatterer at -1.6 nsec occurs in either cockpit configuration and is the most dominant scatterer on the model. In both configurations, the Head Up Display (HUD), is illuminated. The peak from the HUD is very clear in Figures 5-13 and 5-14 at -1.6 nsec. The next contributor is the seat. Clearly, the negative and positive peaks at approximately -1.3 nsec of Figure 5-13 and 5-14 are directly influenced by the presence (or absence) of the seat. Finally, the back of the cockpit scatters in much the same way as the front of the cockpit. (Note that the amplitude of the impulse response is dimensionless. This is a result of the processing.)

The frequency response plots of complex targets are much more difficult to analyze and identify meaningful trends because the RCS of a complex target is a complicated function of frequency. For example, by comparing the frequency responses for the SET and COC configurations, it is almost impossible to determine which configuration scatters the most. The correct answer for this complex target, which is demonstrated in the data, is that either can be the stronger scattering configuration depending upon the frequency. One conclusion which could be determined from the frequency response data is that the SET configuration scatters more than the CAN configuration, as the SET magnitude is always greater or equal to the magnitude from the CAN configuration. The difference in magnitude and the amount contributed by a specific contributor, however, cannot be precisely determined from the total aircraft's frequency response.

To summarize the measurements of the 1/32 scale models, the F-16 and F-15 were measured as described in the test matrix shown in Figure 5-1. The models were first measured at the AFIT range from 8 GHz to 12.4 GHz, where it was discovered that a vertically polarized incident field scattered from the canopy/cockpit area more than a horizontally polarized incident field. The limited success at the AFIT facility was due to the limited bandwidth and small target size. Based on that experience, and to increase the probability of obtaining better data, it was decided to emphasize measurements of the larger model (F-15) with the widest possible bandwidth (2 GHz to 18 GHz) and a vertically polarized incident field.

Test Body Approach

This phase of the study examines the scattering from the canopy/cockpit area by physically isolating the subject area via a test body. There were two reasons and benefits for doing this. First, the size of the canopy/cockpit would be larger than that of the scale model because only the canopy/cockpit needed to fit in the target zone. This reduces the limitations imposed by the range resolution. Another benefit of increasing the size of the test area is an increased effective illuminating frequency. The effective illuminating frequency is the frequency which would illuminate a full scale target in the 'real world' if the ratio between the length of the test wavelength and test target is maintained. The second reason is that the purpose of the test body is to physically isolate the canopy/cockpit, thus eliminating other scattering mechanisms which are not of interest.

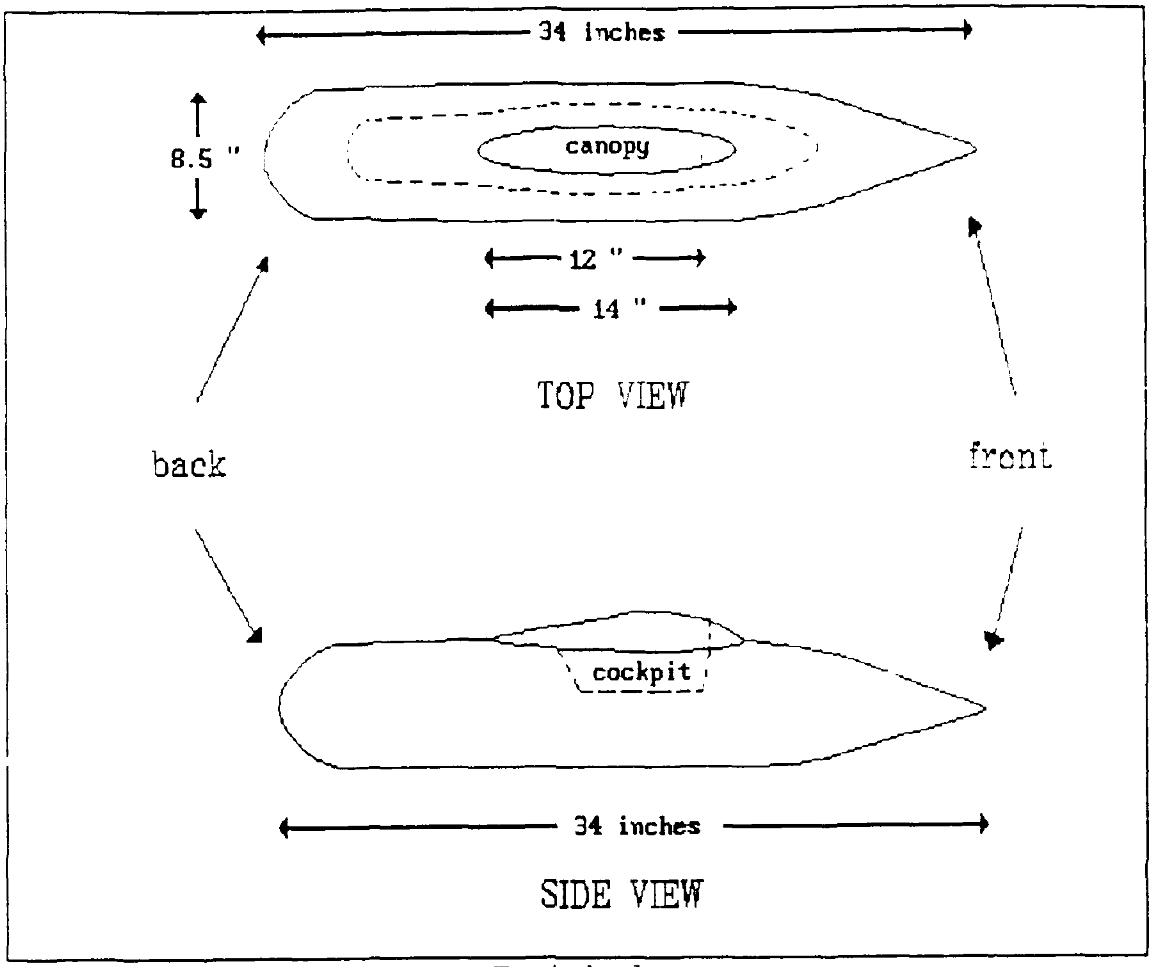
The three major design criteria for the test body were that it: 1. have a very low monostatic RCS (forward direction only), 2. accurately model the canopy and canopy/fuselage interface of the F-16 or F-15 aircraft, and 3. allow the test area (canopy/cockpit area) to fit within the confines of the quiet zone of the AFIT chamber. The canopy had to be removable so a cockpit could be measured. The following paragraphs address the design criteria in further detail.

In anticipation of the acquisition and installment of the broadband antennas (6 GHz to 18 GHz), the test area had to fit in the quiet zone for a frequency of 18 GHz. (The highest frequency dictates the target zone.) The target zone was defined in Chapter II for this frequency as a cylinder of length 3.2 feet and diameter 7.22 inches centered on the target pedestal. Since the cross-range extent of the target zone was obviously the dimension which would limit the size of the test area, the maximum width of the canopy was also restricted by this dimension. The actual dimensions of an F-16 canopy were obtained and it was determined that a 1/5 scale canopy would just fit. A canopy of this scale was not readily available; however, a spare canopy from a 1/10 scale model F-16 was obtained from the Air Force Orientation Group (AFOG) at the Defense Electronic Supply Center (DESC) in Kettering OH. Regarding the third design criteria, the task was reduced to simply building a test body which would allow the canopy/cockpit area to fit in the target zone. Since the target zone and canopy are oblong shapes, it was natural to shape the test body in a similar fashion. In fact, the shape of the test body was designed from the actual dimensions of the fuselage of an F-16. (This is explained further in the discussion of the second design criteria.) The baseline test body was then modified to meet the low RCS design criteria.

The first design criteria was that the test body have a very low frontal RCS. This meant that edges, rough surfaces, discontinuities, changes in the radii of curvature, and other sources of scattering had to be kept to a minimum, especially near the canopy. The front of the cylindrically-shaped test body was smoothed to a pointed cone, and the back of the test body was rounded to a hemisphere. The radius of the test body was designed as small as possible without forcing a drastic change in the curvature of the surface at some other point on the test body. The surface of the test body immediately surrounding the canopy was kept as smooth and consistent as possible. Only at a distance of several wavelengths from the front and back of the canopy did the shape begin to change to the cone, and hemisphere, respectively. The entire test body was painted with conductive silver paint which was acquired from Spray Lat Corporation in Mount Vernon, NY. An ohmmeter was used to make sure the surface was uniform and never above two or three ohms between any two points on the test body.

The second criteria was that the shape of the canopy and the canopy/fuselage interface be as accurate as possible. As previously mentioned, the canopy for the test body was an actual canopy from a 1/10 scale model (very accurate), and the test body was designed from the fuselage dimensions of an F-16, and then altered. The accuracy of the shape of the canopy/fuselage interface was maintained within a perimeter surrounding the canopy for as long a distance as the test body would permit. The top and side views of the test body are shown in Figure 5-15.

The dashed line indicates the perimeter in which the shape of the F-16 fuselage was maintained. Beyond the perimeter, the shape was altered to meet the other design criteria of the test body. Ideally, at the lowest frequency, the shape of the F-16 fuselage should be accurate for at least several wavelengths all around the



Test body
Figure 5-15

canopy/fuselage interface. This distance was achieved at the front and back of the canopy, however, the narrow width of the target zone did not permit the same distance for the perimeter at the sides of the canopy. At the sides, the perimeter extends one inch beyond the canopy/fuselage interface, which, at 6 GHz, is approximately half of a wavelength. The discontinuity caused by the removable canopy was minimized.

On the other hand, no attempt was made to duplicate the cockpit of the F-16, and the SET configuration was not required to be measured. The cockpit was a simple cavity with the same gross dimensions as the actual cockpit.

There were also considerations driven by measurements which affected the design. The test body was to be mounted with a sting mount, which supports the target from the rear and projects the test body in front of the target pedestal. The benefit of this mounting scheme is that a time gate can be used which passes the return from the target while omitting the scattering from the target pedestal. Because the target was in front of the target pedestal, the test body had to be under ten pounds.

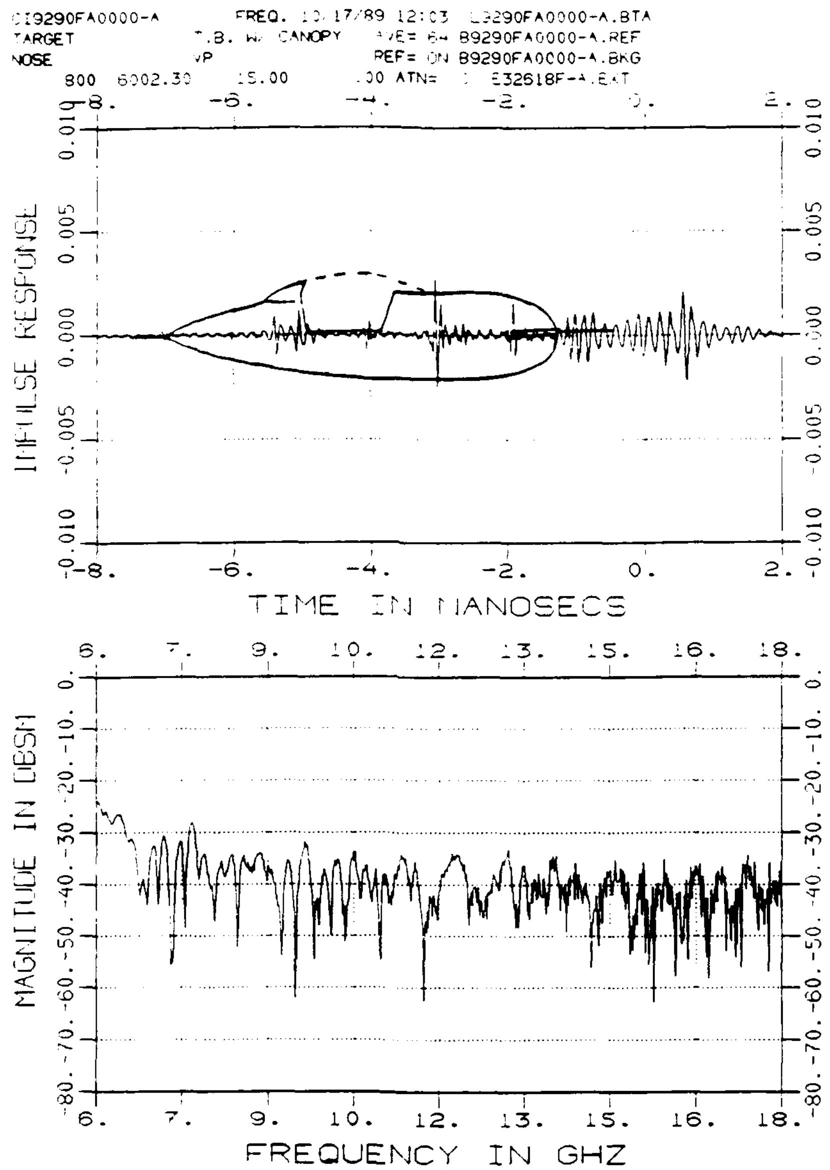
Measurement Results

For the test body measurements, there are two target configurations. These simulate the extreme cases of a metallic and transparent canopy. The SET configuration is not considered. All measurements presented in this section use a vertically polarized incident field (for the same reasons cited for the scale models), although the test body was measured with a horizontally polarized incident field at both facilities. The frequency range was 6 GHz to 18 GHz.

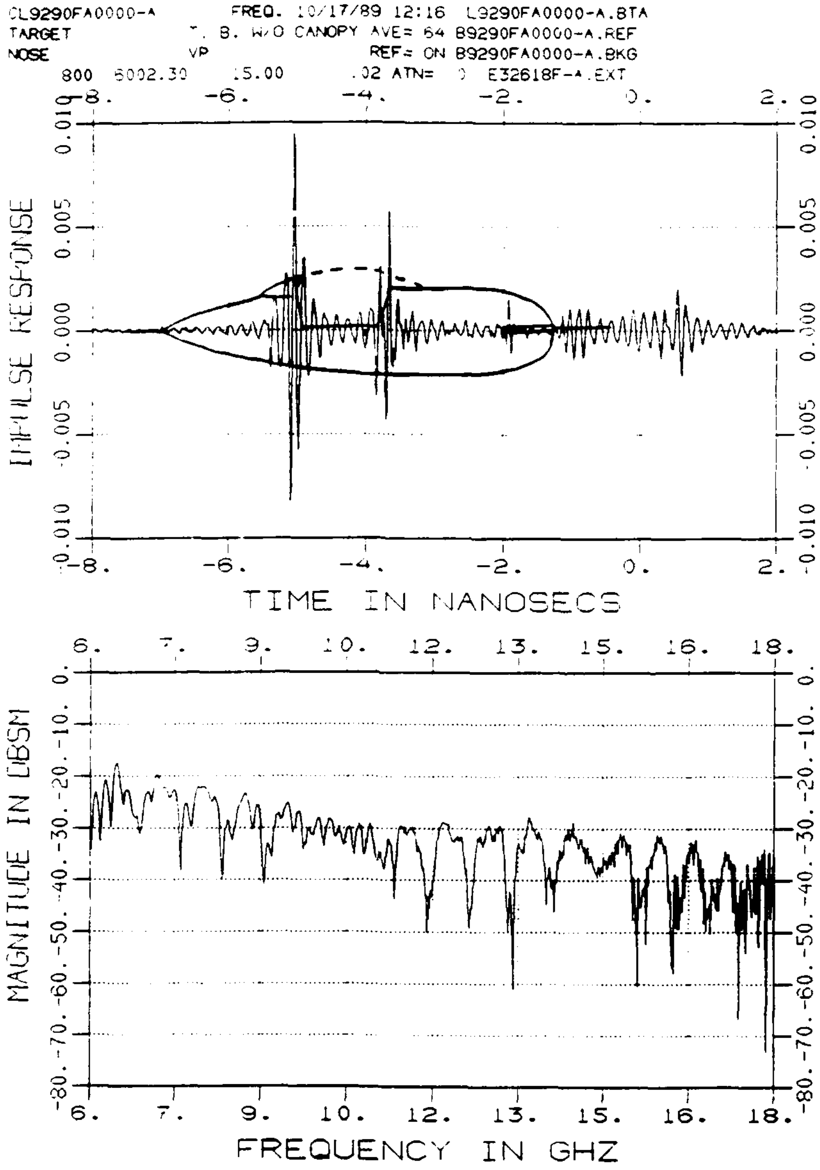
The test body measurements taken at the Barn of the CAN and COC configurations are shown in Figure 5-16 and Figure 5-17, respectively. The benefits alluded to earlier of measuring the test body are now apparent. The relatively sparse returns attest to the success of isolating the canopy/cockpit. The spikes in Figure 5-16a correspond to the discontinuities shown by the template. The peak at -4.0 nsec, however, is not associated with any discontinuity. It is due possibly to a flaw, or non-uniformity in the paint job. Another benefit of the test body is the larger magnitude of the returns. It is apparent by viewing the frequency response data that the COC configuration is approximately 5 dB to 10 dB higher than the CAN configuration. Of course, these frequency response plots contain many undesired signals. A time gate can easily be applied to isolate the desired canopy/cockpit scattering from the undesired signals. (This isolation was not possible in the measurements of the F-16 and F-15 models.) A time gate from -6.0 nsec to -2.0 nsec is applied to the data, and the resulting time domain and frequency response data is provided in Figure 5-18 and Figure 5-19 for the CAN and COC configurations, respectively.

At the lower frequencies, the COC configuration is scattering up to 20 dB more than the CAN configuration. The disparity lessens as the frequency is increased, but is at least 10 dB until about 14 GHz, or approximately two thirds of the plot.

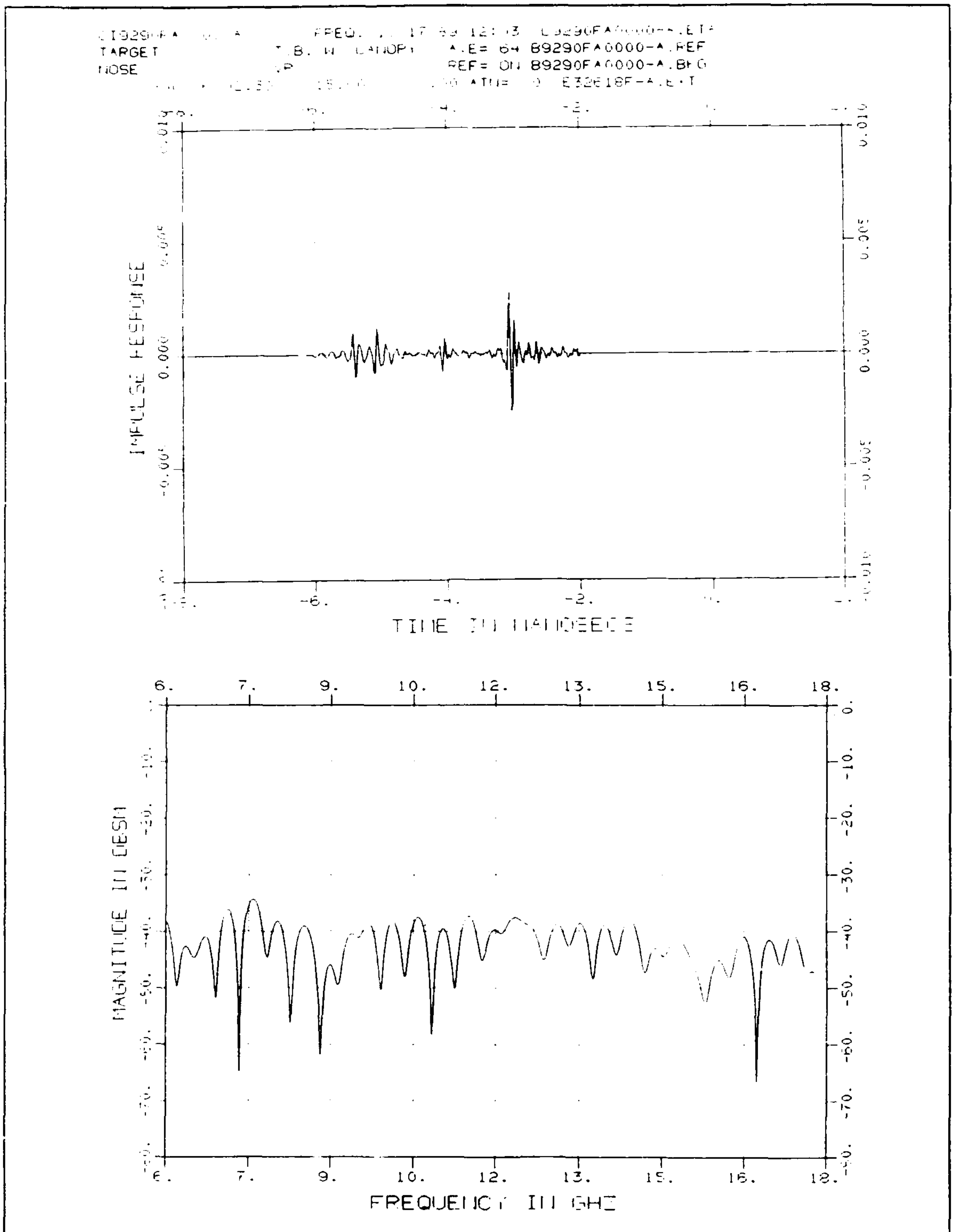
To investigate this further, the CAN configuration was measured from 2 GHz to 18 GHz. The time domain and



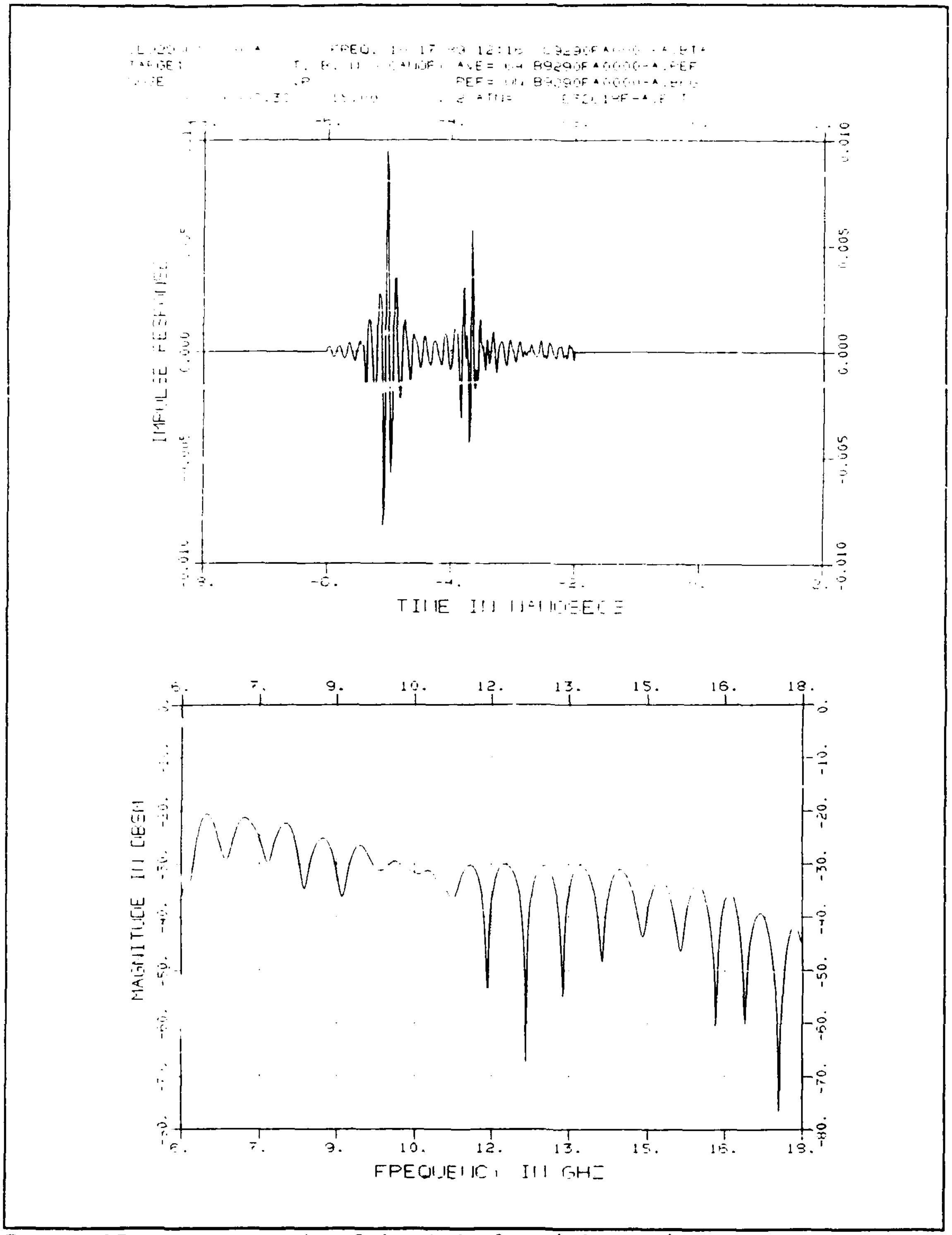
Barn RCS measurement of test body; with canopy, vertical polarization; a) time domain and b) frequency response
Figure 5-16



Barn RCS measurement of test body; cockpit, vertical polarization; a) time domain and b) frequency response
Figure 5-17



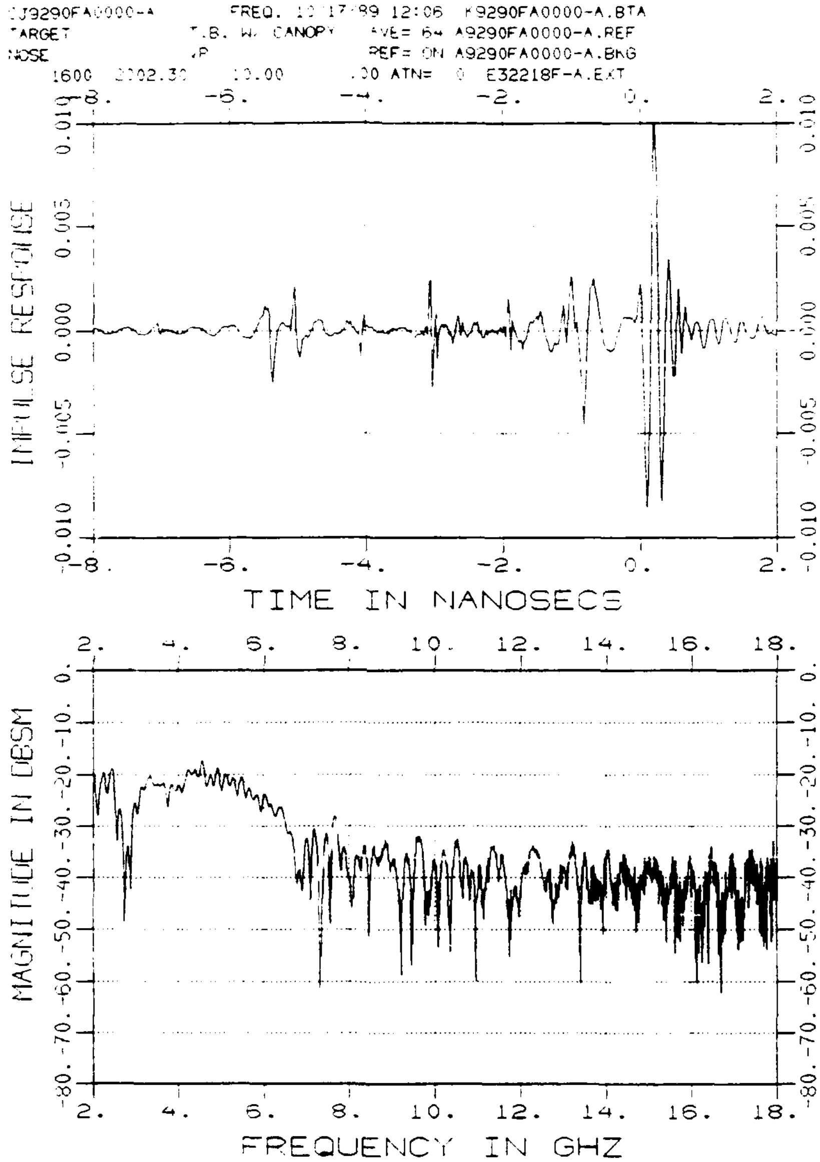
Barn RCS measurement of test body with a time gate (-6 to -2 nsec), canopy, vertical polarization; a) time domain and b) Frequency Response
Figure 5-18



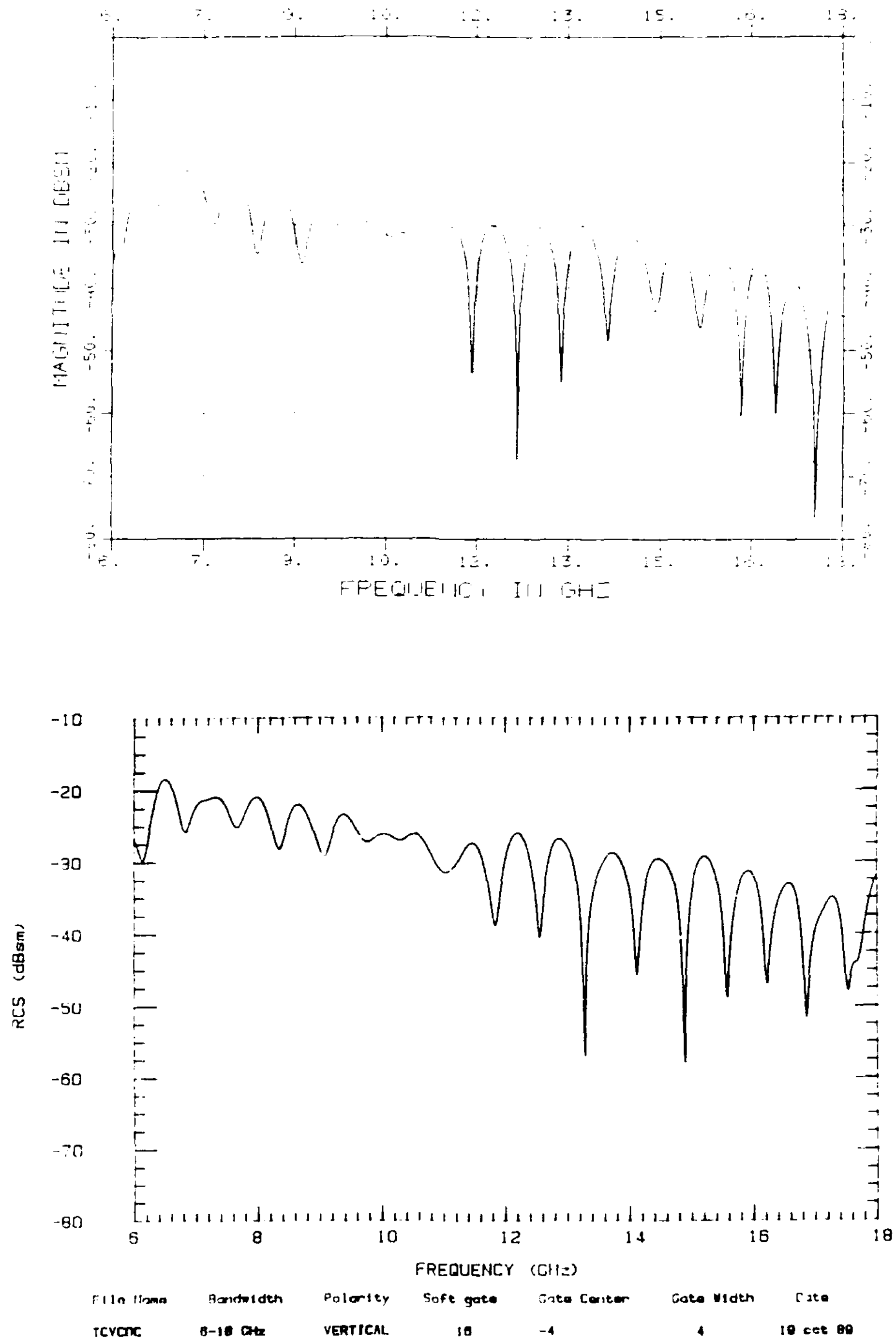
Barn RCS measurement of test body with a time gate (-6 to -2 nsec); cockpit, vertical polarization, a) time domain and b) frequency domain
Figure 5-19

frequency response of this measurement are shown in Figure 5-20. Notice the significant amount of energy between 2 GHz and 6.5 GHz. The cause of the low frequency energy appears to be the large spike which occurs at approximately 0.25 nsec in the time domain plot. (In comparing the same measurement from 6 to 18 GHz (Figure 5-16a), the scattering at 0.25 nsec is present, but not nearly as strong.) This scatterer occurs well beyond the temporal location of the test body, and is therefore not caused by any direct scattering from the test body. The next concern is to identify the reason for this scattering. Based on the temporal location, the scattering may be a direct return from the sting mount, or could be related to energy creeping around the rear of the test body. This energy could proceed directly back to the observer, or intercept the target pedestal which would cause additional scattering. Whatever the cause of the return, it is of absolutely no interest to this study.

The measurements of the test body were also taken at the AFIT chamber, with both polarizations and a frequency range of 6 GHz to 18 GHz. Despite the relative complexity of the target and the data processing, the results are amazingly similar, as seen in Figure 5-21. This figure shows the frequency responses taken at each facility of the test body without a canopy. (Figure 5-21a is a repeat of Figure 5-19b.) The patterns and levels are virtually identical.



Barn measurement of test body with canopy, 2 to 18 GHz, vertical polarization; a) time domain and b) frequency response
Figure 5-20



Frequency response of test body without canopy, 6 to 18 GHz, vertical polarization; a) the Barn and b) AFIT
Figure 5-21

The only difference between the measurements is the depth of the nulls, which is greater at the Barn because of the greater sensitivity. Target alignment, however, is always a possibile source of error.

The 1/10 scale factor of the test body can be used to approximate the level of scattering from a full scale canopy/cockpit. The level of scattering from a full-scale target is roughly -20*log(scale factor) dB higher than the scaled target. Thus, for a scale factor of 1/10, the full scale vehicle would scatter 20 dB higher than the 1/10 scale model. For example, Figure 5-16b indicates the magnitude of the return for the 1/10 scale canopy at slightly past 12 GHz is -35 dBsm. The magnitude of the return from a full scale canopy, then, would be -15 dBsm. As previously mentioned, the COC configuration is scattering 10 to 20 dB higher than the CAN configuration. Obviously, the difference in scattering between the same configurations on a full scale aircraft would still be 10 to 20 dB. Of course, the full scale vehicle is a much more complicated geometry than the relatively simple geometry of the test body.

Conclusion

The problem statement for this thesis was twofold; consequently, observations and recommendations for each task are given separately.

AFIT Chamber Upgrade

As stated earlier, the first task was to complete the automation of the AFIT RCS measurement range. New software was needed to control recently acquired microwave hardware. The new hardware had certain new capabilities which the controlling software exploited. A software package, called ARMS (AFIT Radar Cross Section Measurement Software) was generated which not only achieved the objectives defined at the onset of the thesis, but was flexible enough to allow for continual change and improvement. The measurement procedure produces excellent results, as evidenced by the strong comparison with measurements from the WRDC anechoic chamber. As with any project involving software, however, the number of possible improvements is seemingly endless.

Most of the recommendations for improving the ARMS code involve features; that is, the ability to process and display the data. For a pattern cut, a relatively easy improvement would be to let the user select the start and stop angles, and the resolution of the data. A convenient (and legitimate) improvement would be to permanently store the background measurement in a file which could be recalled at any time. Another improvement would be to allow the user to set the start and stop times of the gate, as opposed to selecting a gate center and gate span.

Canopy/Cockpit Measurements

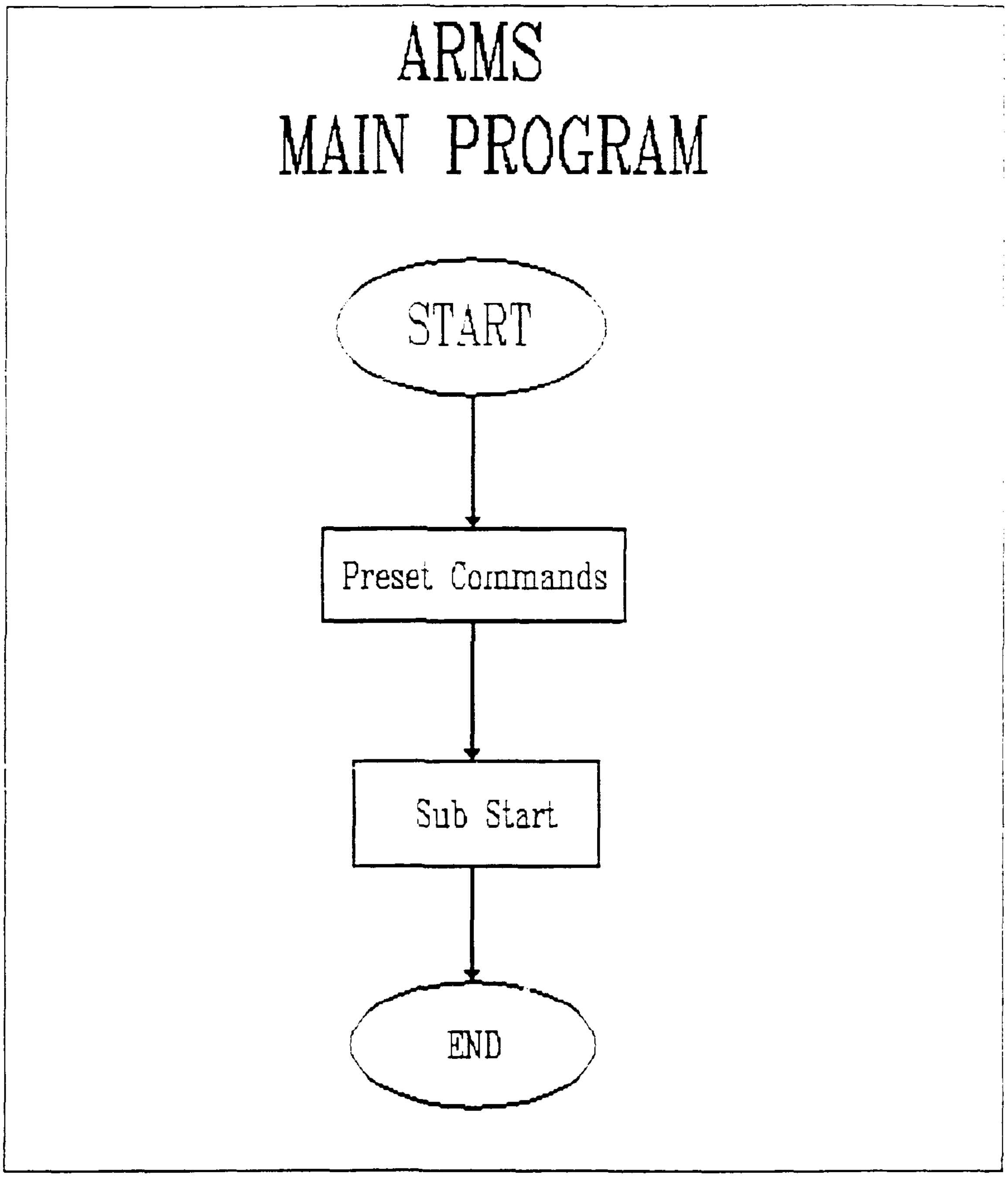
The second task was the investigation of the effect of a metallic versus a transparent canopy on the total RCS of an aircraft. The scattering from these extreme canopies was investigated by measuring a scaled version of a realistic canopy which was removable from the target.

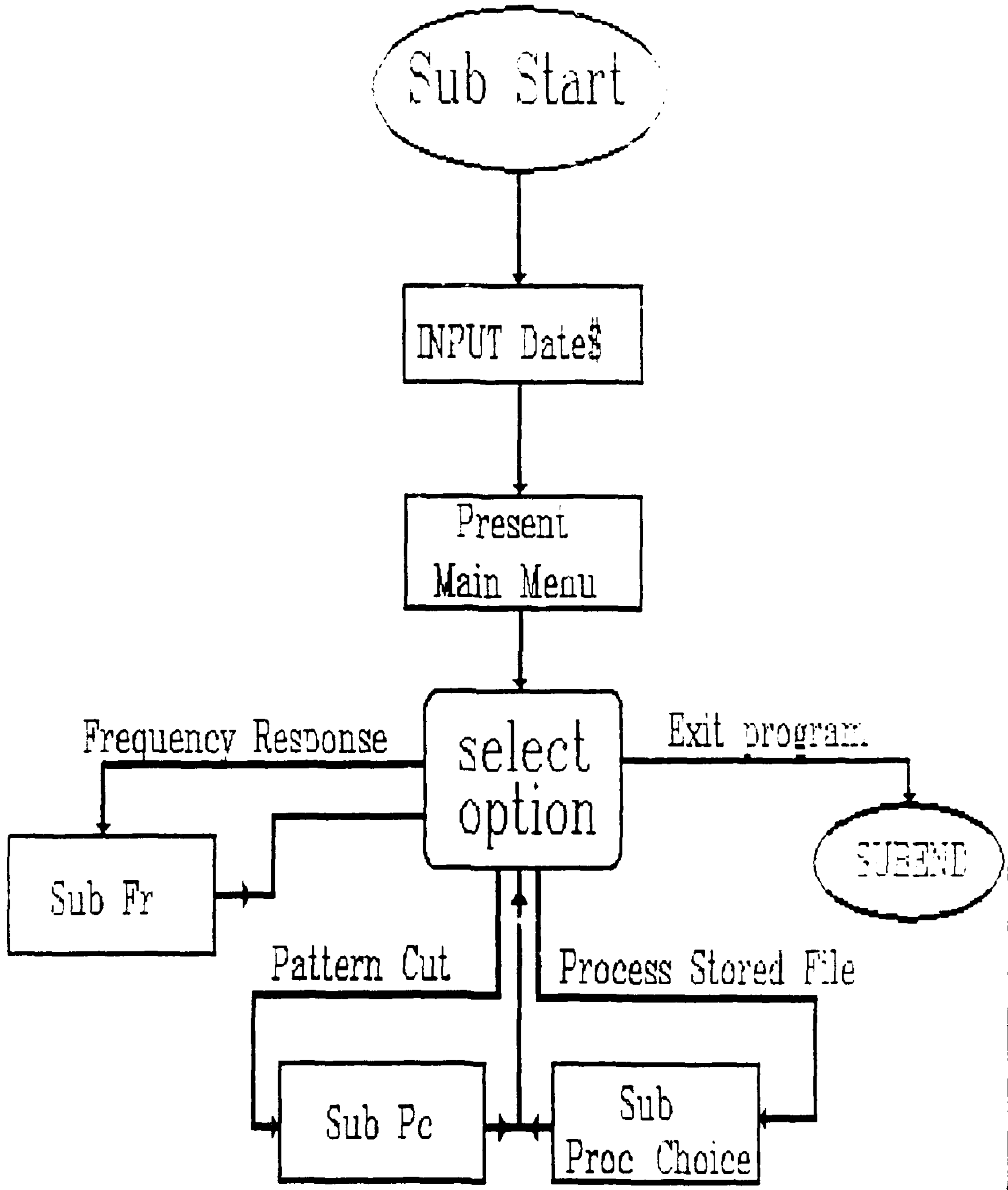
The scale model measurements revealed a small but measurable difference in the RCS of the two configurations. The metallic canopy scattered less than a transparent canopy, which was simulated by an exposed cockpit. In the context of the entire aircraft, the frequency responses of the aircraft models were close, as each may be higher or lower depending on the frequency.

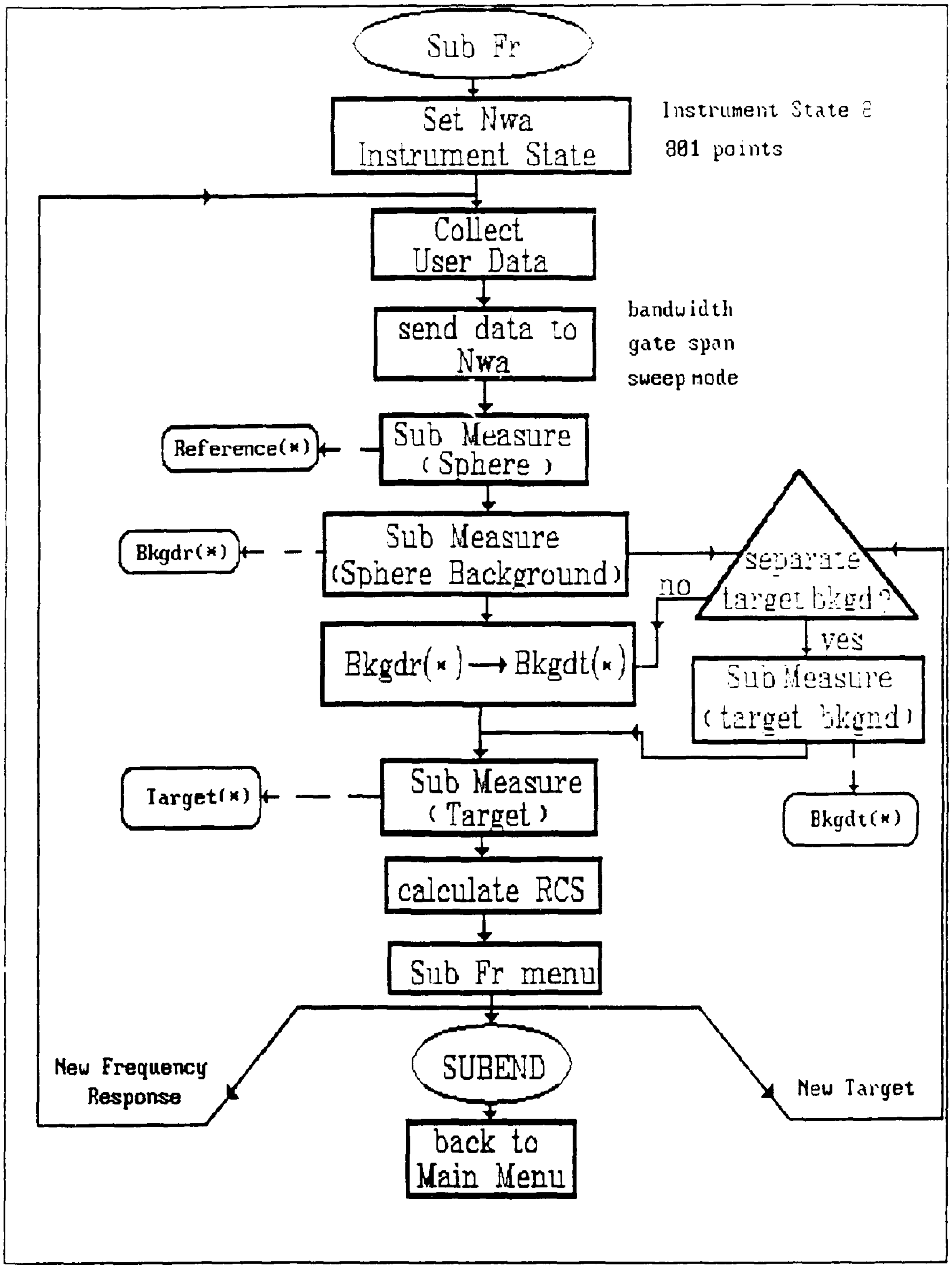
The secondary objective was to investigate the scattering from just the canopy/cockpit, without the complications of the scattering from the rest of the aircraft. As expected, the difference in the RCS between the two configurations was demonstrated more clearly. There was a 10 to 20 dB change between the CAN and COC configuration. Obviculsy, the difference in RCS of these two configurations on a full-scale version of this test canopy would still be 10 to 20 dB.

There is interest and value in learning more about this subject. While the results of the measurement portion of the thesis effort may or may not be surprising, they do define the upper and lower bounds on the scattering, and present the limitations and benefits of the various approaches. Further work should investigate materials and emphasize different levels of conductivity of the canopy, as opposed to the two extreme cases studied here. Other possibilities include determining the effect of different canopy constructions on the RCS of the canopy.

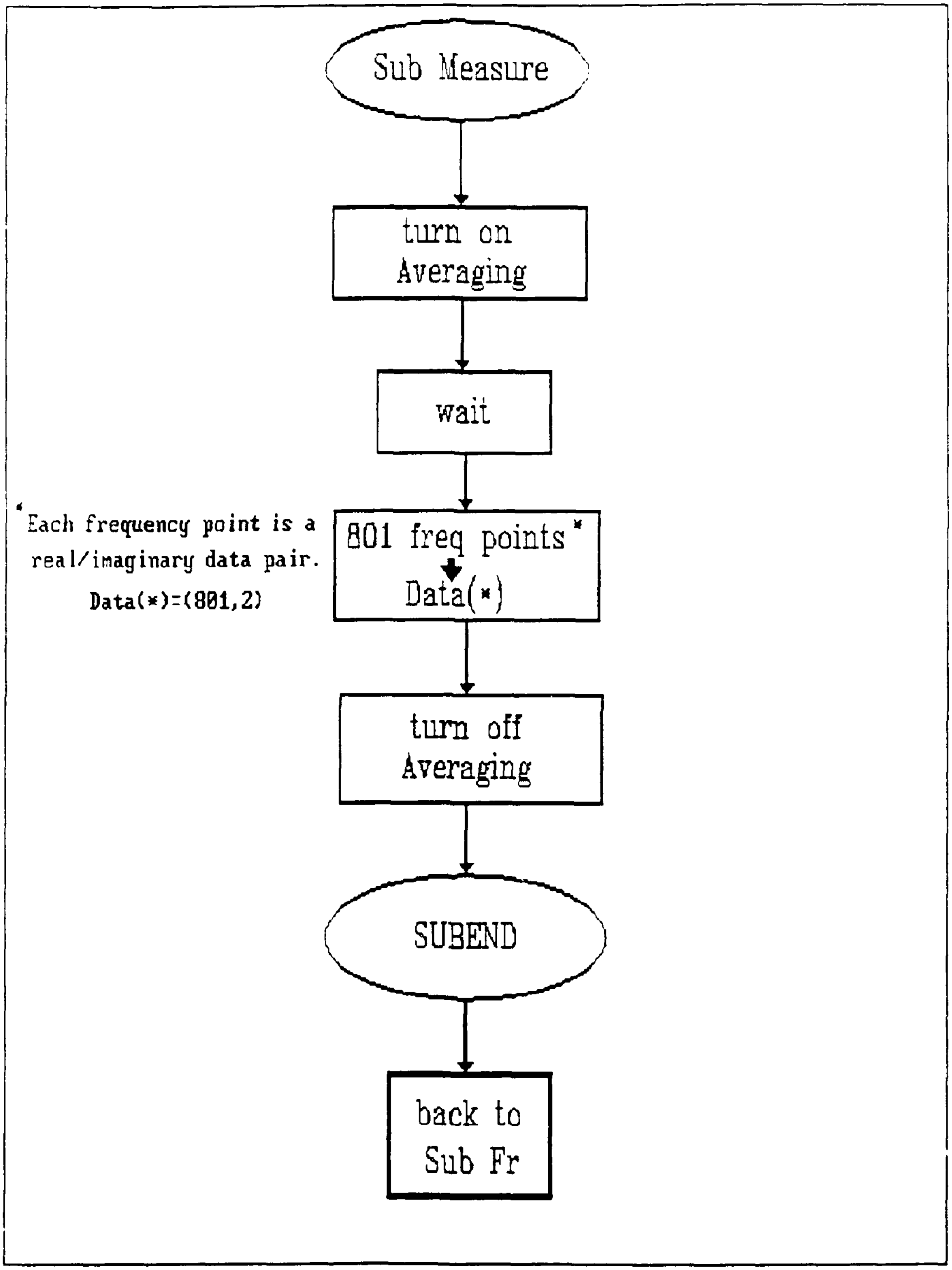
Appendix A: Flow Charts of Subroutines in ARMS Code

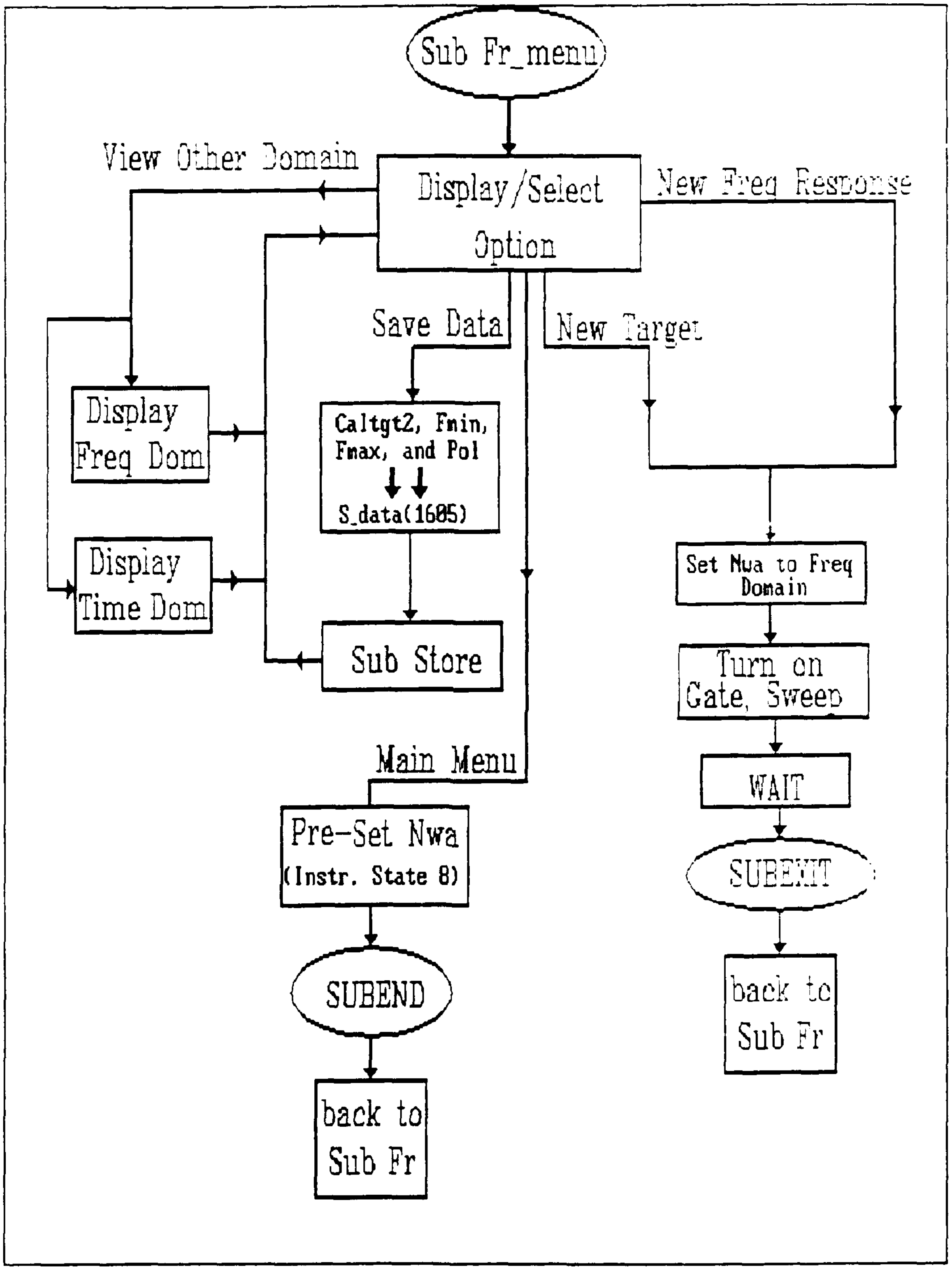



Sub Start
INPUT Date$
Present
Main Menu
select
option
Frequency Response
Exit program
Sub Fr
Pattern Cut
Process Stored File
Sub Pc
Sub
Proc Choice

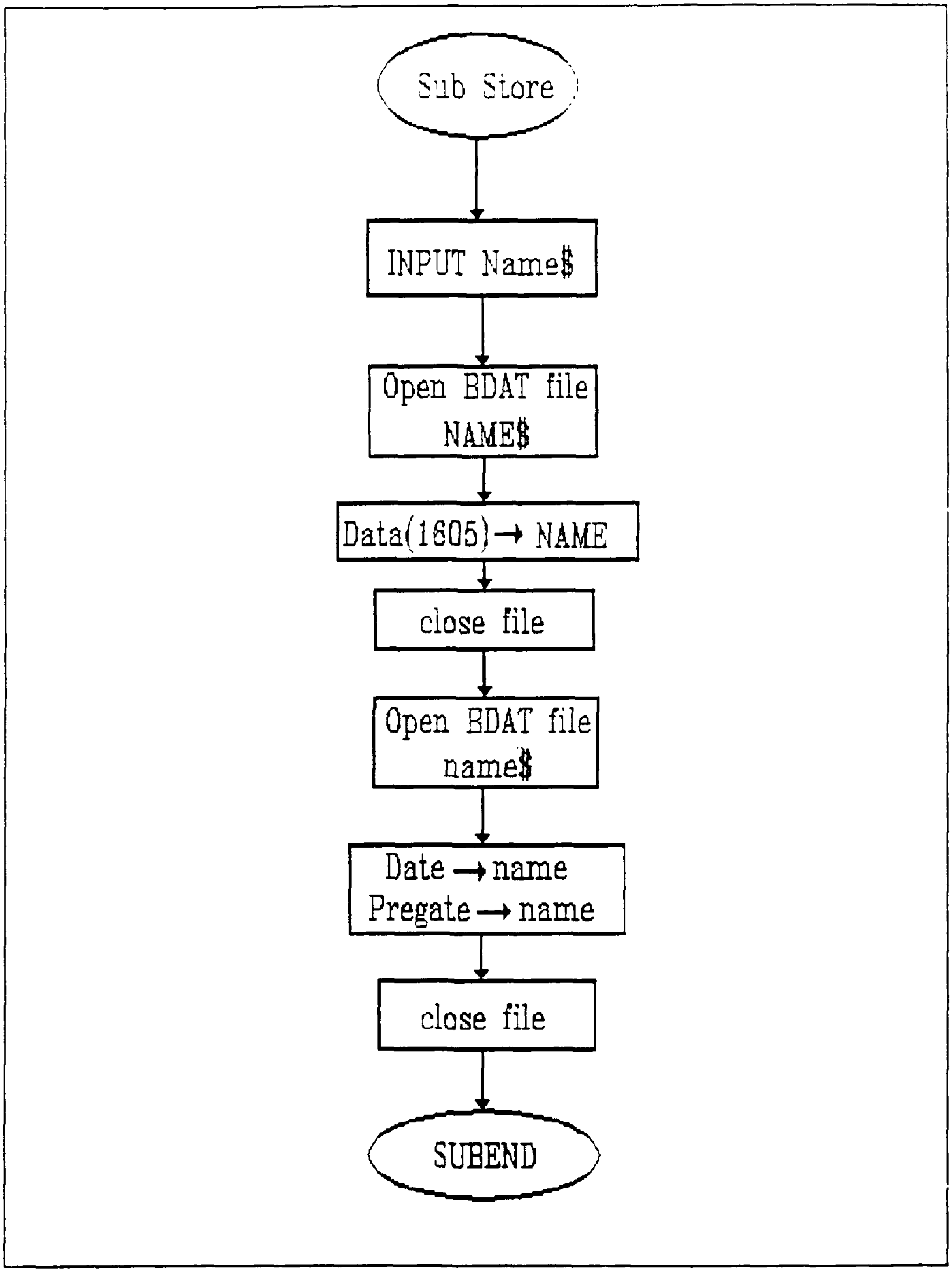


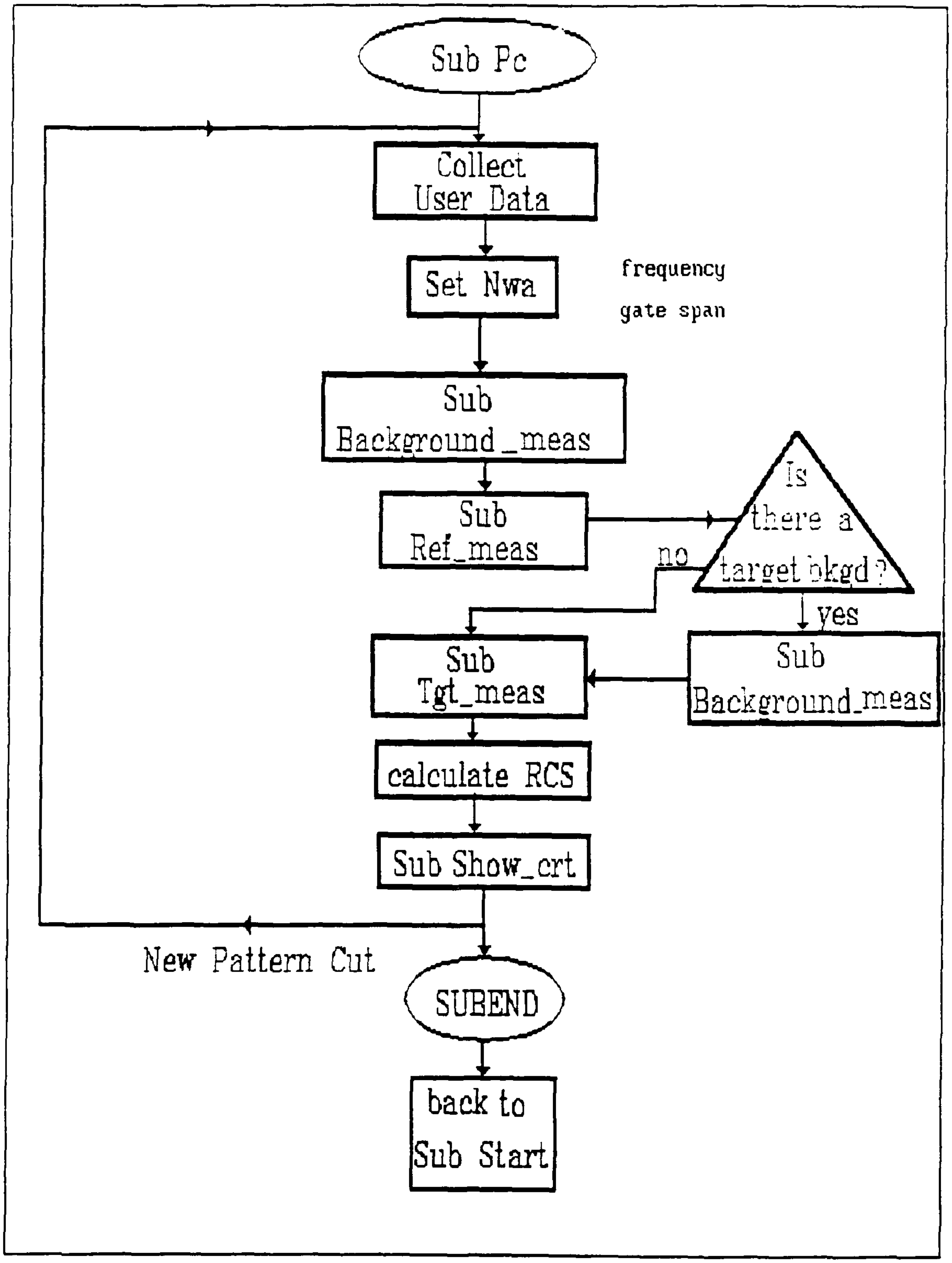
Sub Fr
Set Nwa Instrument State
Instrument State 8
801 points
Collect User Data
send data to Nwa
bandwidth
gate span
sweep mode
Reference(*)
Sub Measure (Sphere)
Bkgdr(*)
Sub Measure (Sphere Background)
separate target bkgd?
no
yes
Bkgdr(*) → Bkgdt(*)
Sub Measure (target bkgnd)
Target(*)
Sub Measure (Target)
Bkgdt(*)
calculate RCS
Sub Fr menu
New Frequency Response
SUBEND
New Target
back to Main Menu


Sub Measure
turn on Averaging
wait
*Each frequency point is a real/imaginary data pair. Data(*)=(801,2)
801 freq points*
Data(*)
turn off Averaging
SUBEND
back to Sub Fr

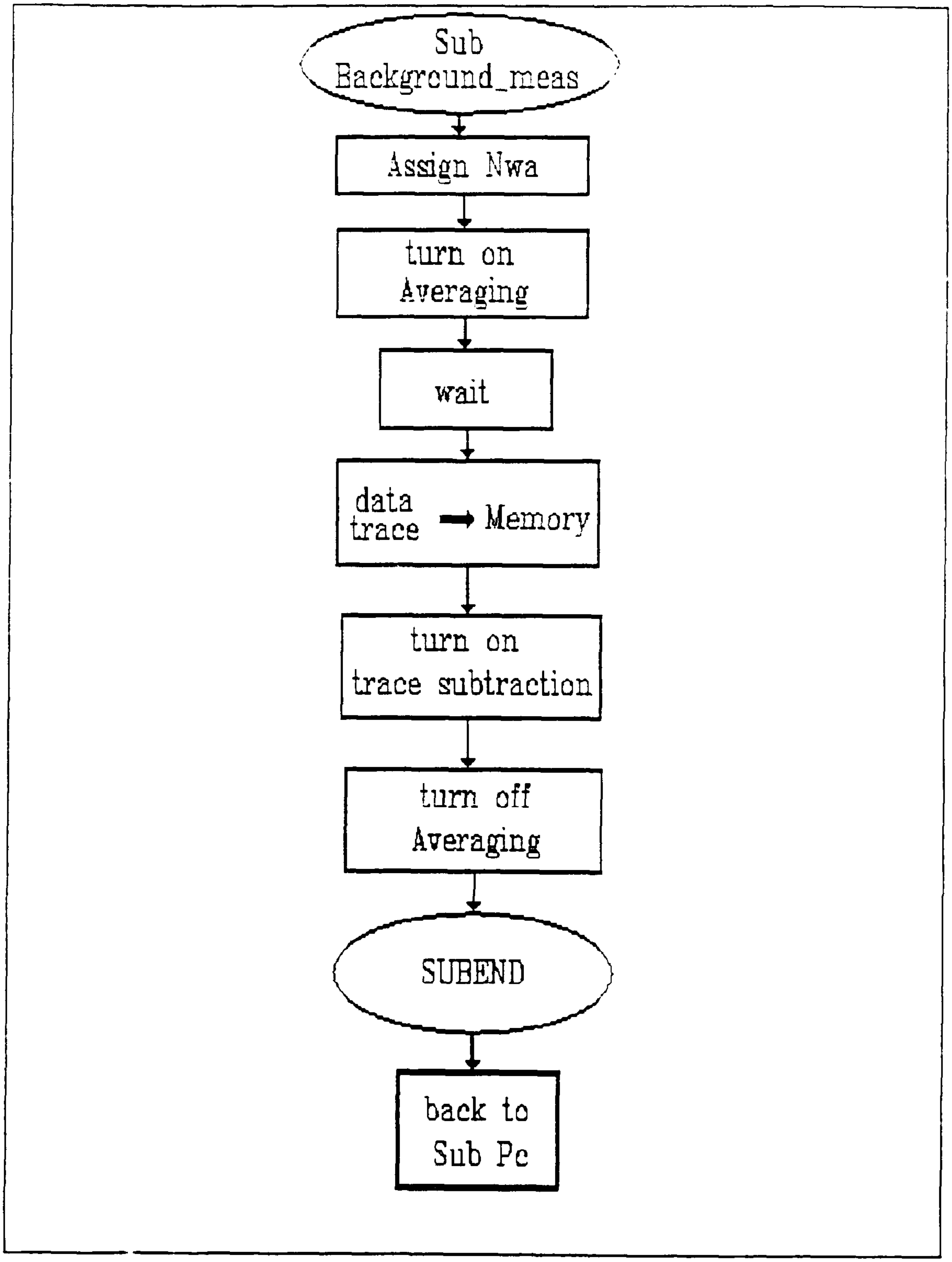


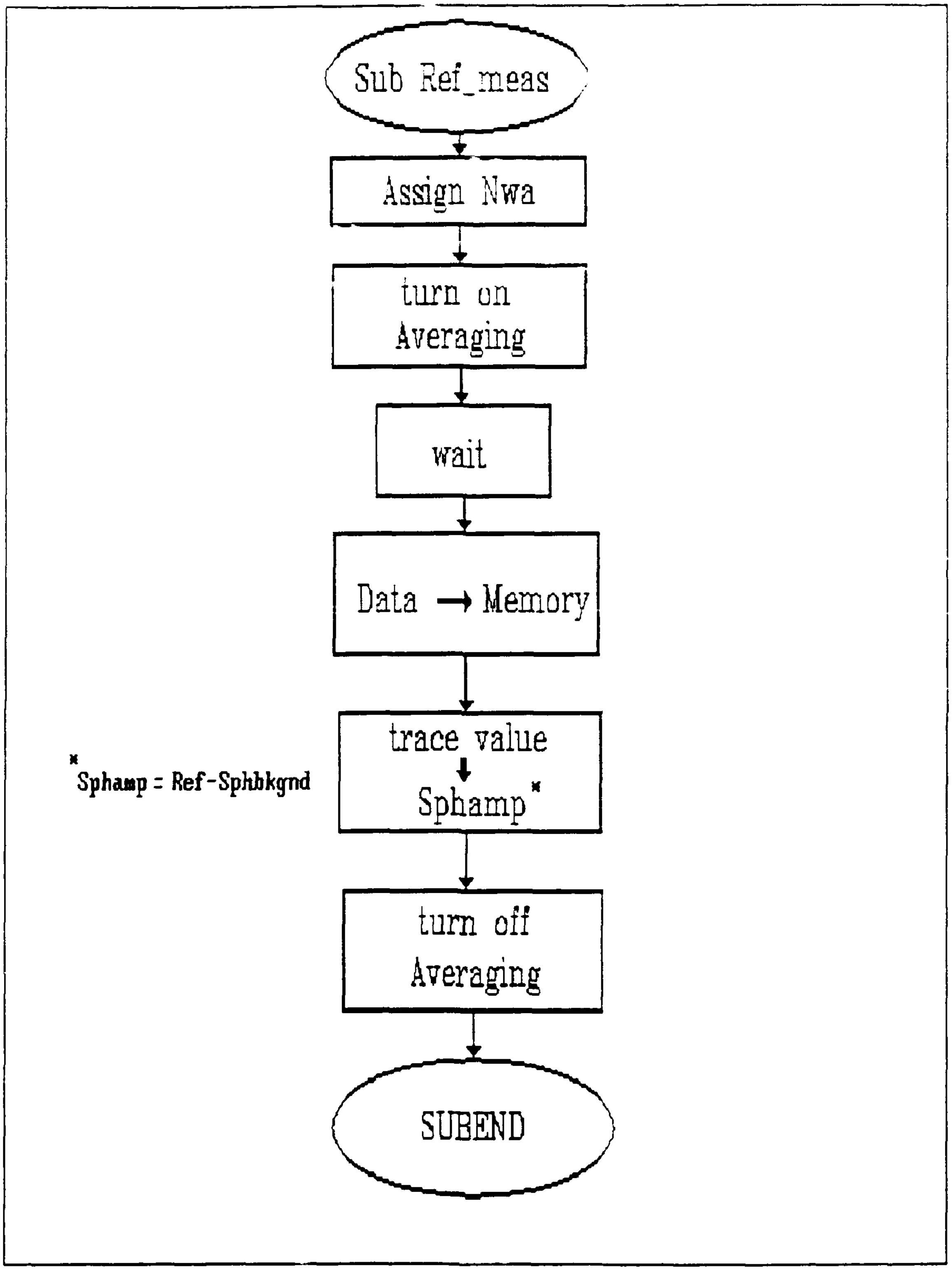
Sub Fr_menu
Display/Select Option
View Other Domain
New Freq Response
Save Data
New Target
Display Freq Dom
Display Time Dom
Caltgt2, Fmin, Fmax, and Pol
S_data(1605)
Sub Store
Set Nwa to Freq Domain
Turn on Gate, Sweep
WAIT
SUBEXIT
back to Sub Fr
Main Menu
Pre-Set Nwa (Instr. State 8)
SUBEND
back to Sub Fr

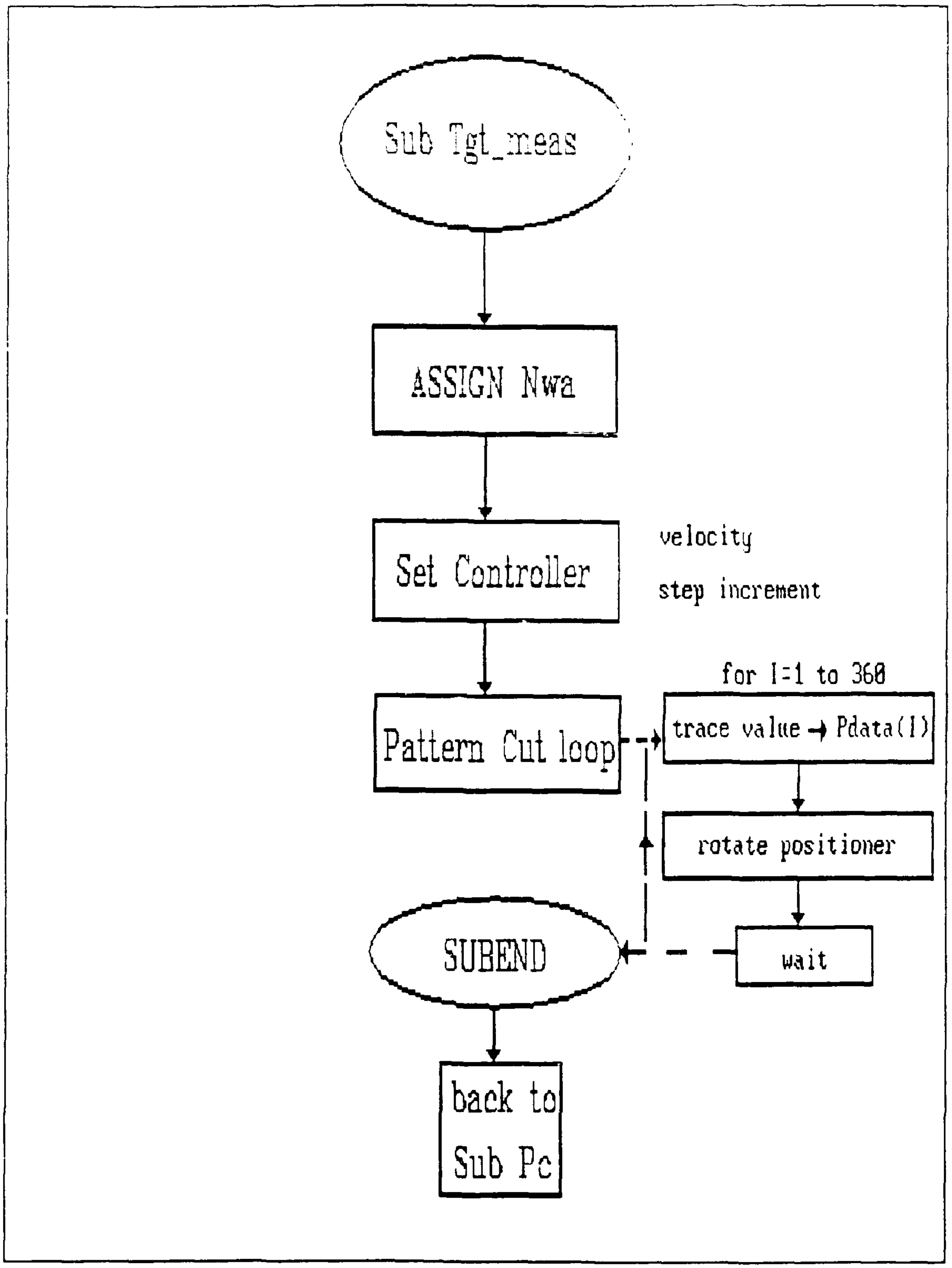

Sub Store
INPUT Name$
Open BDAT file NAME$
Data(1605) → NAME
close file
Open BDAT file name$
Date → name
Pregate → name
close file
SUBEND

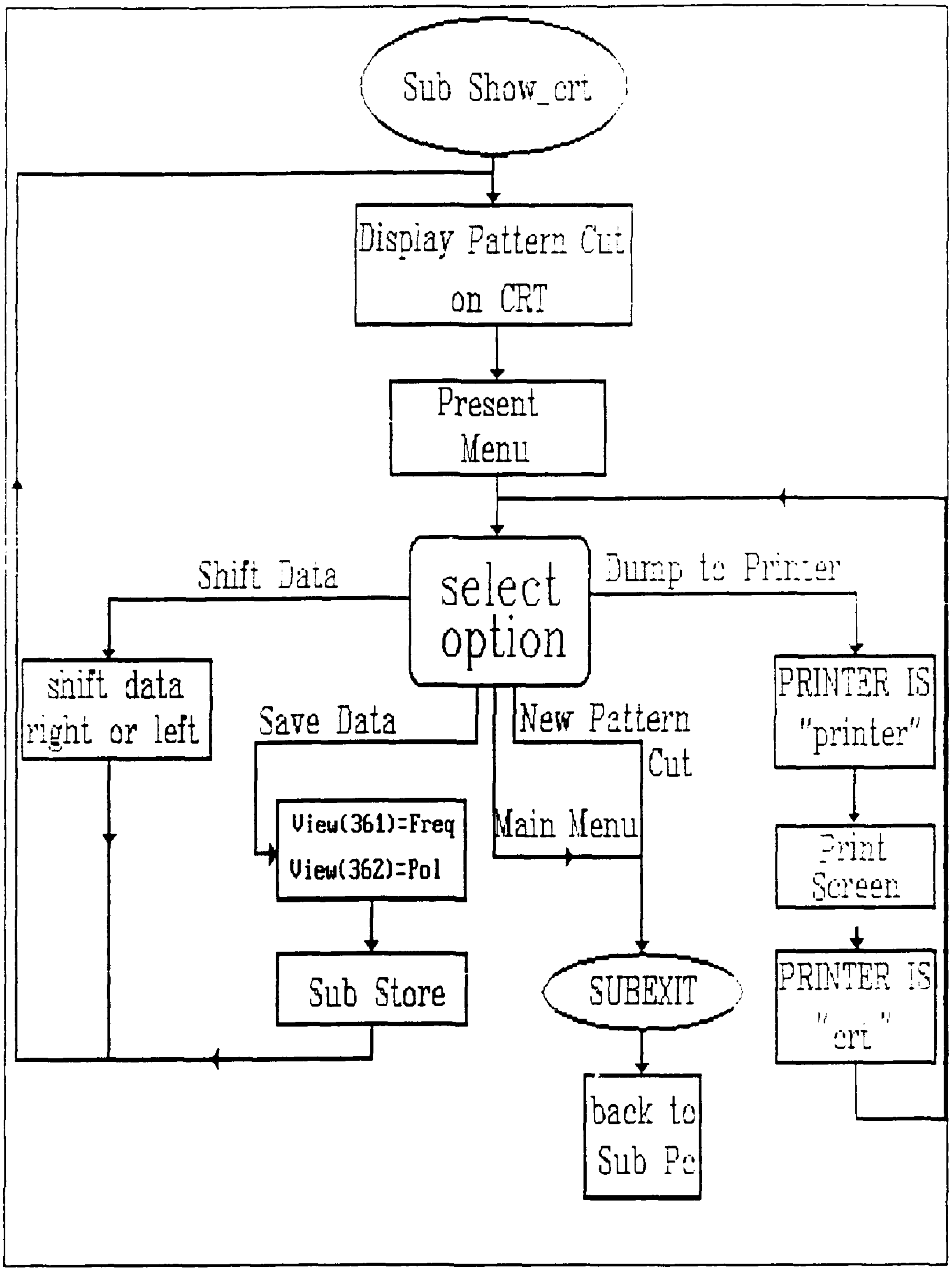


Sub Pc
Collect User Data
Set Nwa
frequency
gate span
Sub Background_meas
Sub Ref_meas
Is there a target bkgd?
no
yes
Sub Tgt_meas
Sub Background_meas
calculate RCS
Sub Show_crt
New Pattern Cut
SUBEND
back to Sub Start

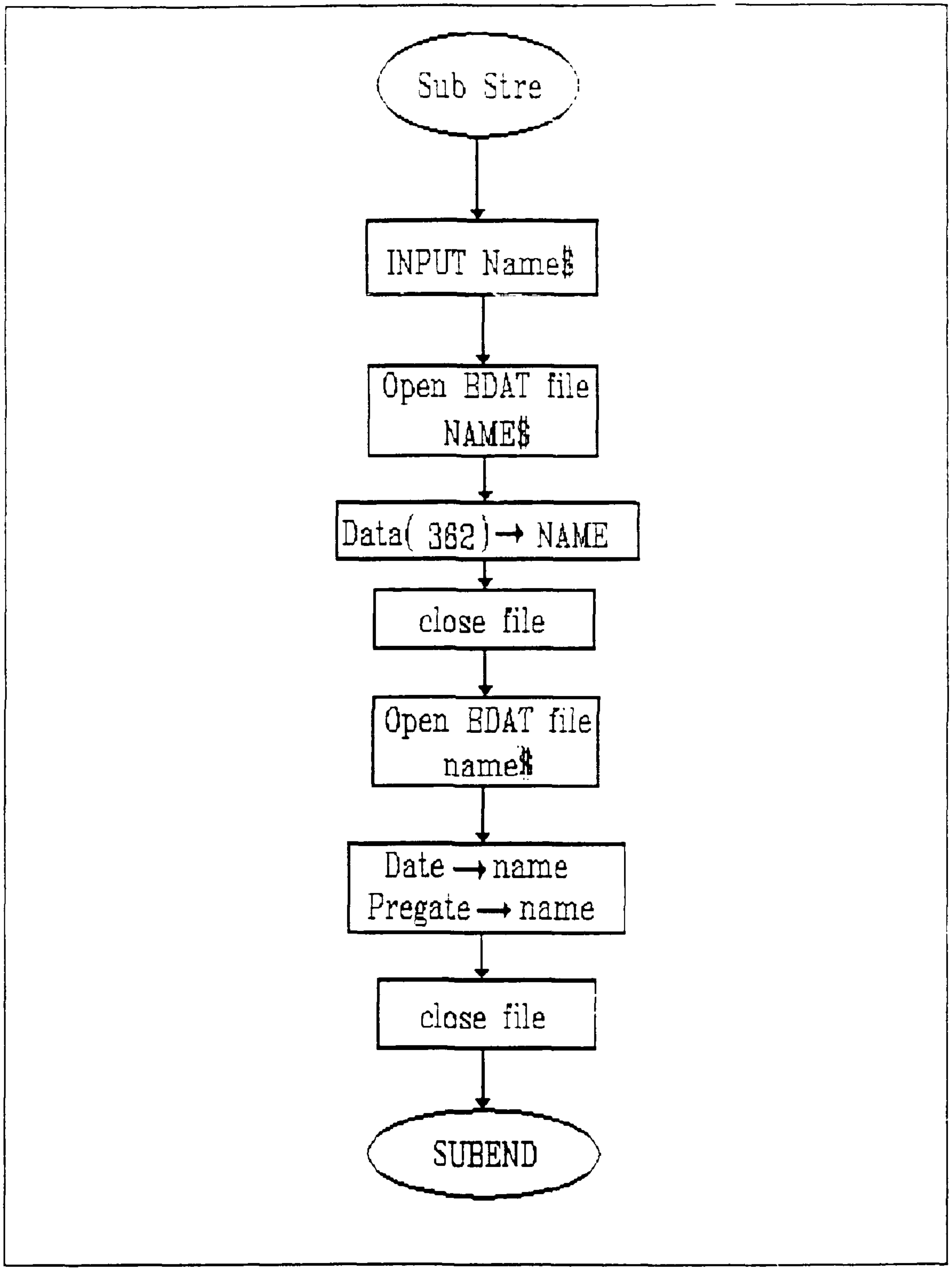

Sub
Background_meas
Assign Nwa
turn on
Averaging
wait
data
trace
Memory
turn on
trace subtraction
turn off
Averaging
SUBEND
back to
Sub Pc


Sub Ref_meas
Assign Nwa
turn on Averaging
wait
Data → Memory
trace value
Sphamp*
*Sphamp = Ref-Sphbkgnd
turn off Averaging
SUBEND

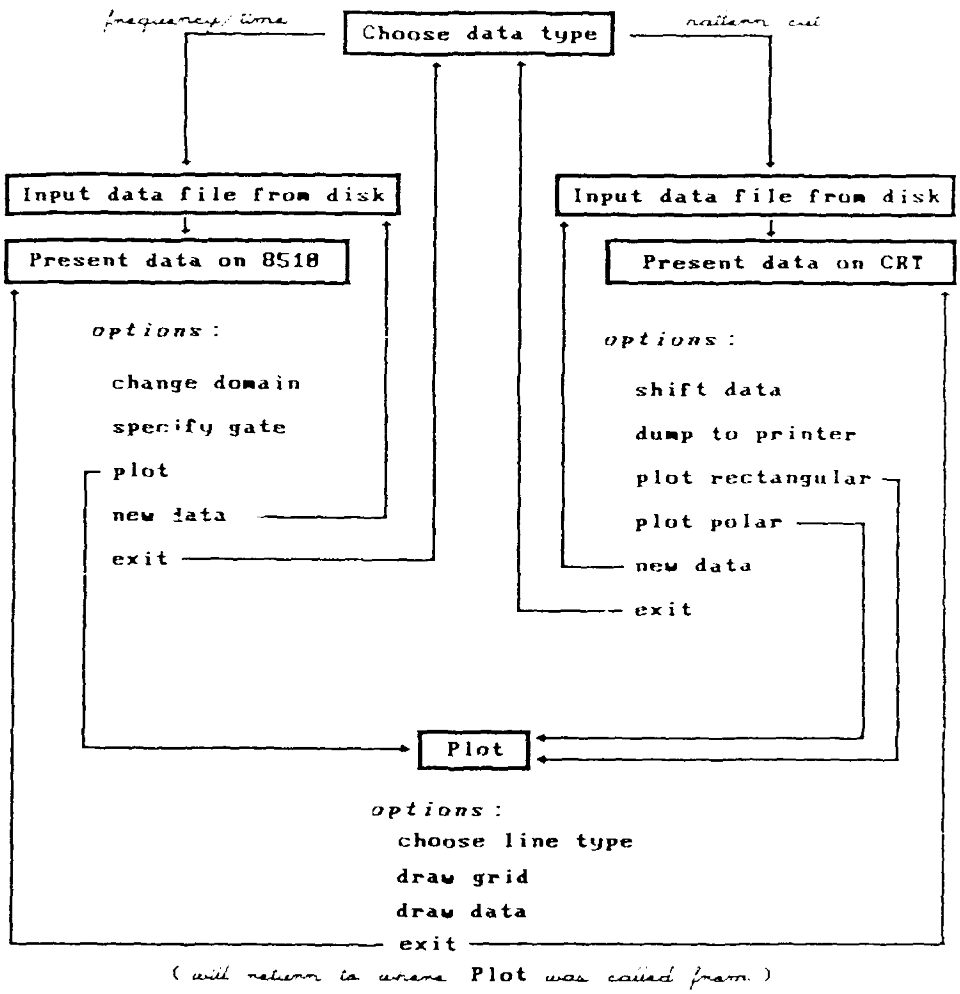

Sub Tgt_meas
ASSIGN Nwa
Set Controller
velocity
step increment
Pattern Cut loop
for I=1 to 360
trace value → Pdata(I)
rotate positioner
wait
SUBEND
back to
Sub Pc



Sub Show_crt
Display Pattern Cut on CRT
Present Menu
select option
Shift Data
shift data right or left
Save Data
View(361)=Freq
View(362)=Pol
Sub Store
New Pattern Cut
Main Menu
SUBEXIT
back to Sub Pc
Dump to Printer
PRINTER IS "printer"
Print Screen
PRINTER IS "crt"



Sub Stre
INPUT Name$
Open BDAT file NAME$
Data(362)→ NAME
close file
Open BDAT file name$
Date → name
Pregate → name
close file
SUBEND



Choose data type
frequency/ time
pattern cut
Input data file from disk
Present data on 8510
options :
change domain
specify gate
plot
new data
exit
Input data file from disk
Present data on CRT
options :
shift data
dump to printer
plot rectangular
plot polar
new data
exit
Plot
options :
choose line type
draw grid
draw data
exit
(will return to where Plot was called from)

Appendix B: ARMS Code

```
10     ! AFITRCS              Version 1.0  May 1989
20     !LINES 10 TO 100 ARE THE MAIN PROGRAM
30     OPTION BASE 1
40     INTEGER Preamble,Size,No_points,Cals,Cm
50     MASS STORAGE IS ":INTERNAL,4,1"
60     OFF KEY
70     CALL Clear_crt
80     CALL Start(Date$)
90     PRINT "You are now back in BASIC."
100    END
110    !
120    !THIS SUBROUTINE IS THE MAIN MENU FOR 'AFITRCS'.
130    !
140    SUB Start(Date$)
150    PRINT ""
160    CALL Clear_crt
170    INPUT "Enter today's date.",Date$
180 Start:DISP CHR$(129)
190    CALL Clear_crt
200    PRINT ""
210    PRINT ""
220    PRINT "       K0 - Frequency response"
230    PRINT ""
240    PRINT "          K2 - Pattern Cut"
250    PRINT ""
260    PRINT "          K4 - Process/Plot stored files"
270    PRINT ""
280    PRINT "       K7 - Back to BASIC"
290    PRINT ""
300    PRINT ""
310    ON KEY 0 LABEL "Freq. Response" GOTO C_fr
320    ON KEY 2 LABEL " Pattern Cut " GOTO C_pc
330    ON KEY 4 LABEL " Plot / Proc " GOTO C_pr
340    ON KEY 7 LABEL "Back to BASIC " GOTO C_exit
350    ON KEY 1 GOTO Idle
360    ON KEY 3 GOTO Idle
370    ON KEY 5 GOTO Idle
380    ON KEY 6 GOTO Idle
390    ON KEY 8 GOTO Idle
400    ON KEY 9 GOTO Idle
410 Idle:DISP "Please hit the appropriate soft key."
420    GOTO Idle
430 C_fr: OFF KEY
440    CALL Fr(Date$)
450    GOTO Start
460 C_pc: OFF KEY
470    CALL Pc(Date$)
480    GOTO Start
490 C_pr: OFF KEY
500    CALL Proc_choice
510    GOTO Start
520 C_exit: OFF KEY
530    CALL Clear_crt
540    SUBEND
550    !
560    !THIS SUBROUTINE IS THE MAIN MENU FOR THE FREQUENCY RESPONSE.
570    !
580    SUB Fr(Date$)
590    ASSIGN @Nwa TO 716
600    ASSIGN @Nwa_data TO 716;FORMAT OFF
610    OPTION BASE 1
```

```
620    [illegible] @Nwa:"RECA8:FIN801:"
630    INTEGER Preamble,Size,Cals,No_points,Dr
640    INT Bkgdt(801,2),Bkgtr(801,2),Reference(801,2),Target(801,2),Cal_tgt(801,2
),Ex_sphere(801,2),Cal_tgt2(801,2),E_data(1602)
650    INT Data(801,2),Bkgdr(801,2),S_data(1605),Referenc(801,2)
660    [illegible]
670 Next: CALL Clear_crt
680    PRINT "Choose the range for your frequency response."
690    PRINT ""
700    PRINT ""
710    PRINT "Enter"
720    PRINT ""
730    PRINT "        1 ............ 2 to 18 GHz"
740    PRINT "        2 ............ 7 to 12.4 GHz"
750    PRINT "        3 ............ 6 to 18 GHz."
760    PRINT ""
770    PRINT "Default is 8 to 12.4 GHz."
780    Frange=2
790    INPUT Frange
800    IF Frange<>1 AND Frange<>2 AND Frange<>3 THEN GOTO 670
810    Pol$=""
820    INPUT "Type the polarization of the field (H or V : Default is Horizonta
l)",Pol$
830    IF Pol$<>"H" AND Pol$<>"V" AND Pol$<>"" THEN GOTO 820
840    IF Pol$="" OR Pol$="H" THEN
850      Pol$="HORIZONTAL"
860      Pol=0
870    ELSE
880       Pol$="VERTICAL"
890       Pol=1
900    END IF
910    Sweep$=""
920    INPUT "Type 'S' for step sweep, or 'R' for ramp sweep (Ramp is default).",
Sweep$
930    IF Sweep$<>"S" AND Sweep$<>"R" AND Sweep$<>"" THEN GOTO 920
940    IF Sweep$="S" THEN Sweep$="STEP"
950    IF Sweep$="R" OR Sweep$="" THEN Sweep$="RAMP"
960    Aver=32
970    INPUT "Enter the averaging factor. (Between 1 and 4096: 32 is default)",
Aver
980    IF Aver<1 OR Aver>4096 THEN GOTO 960
990    Tmegte=7
1000   INPUT "What time gate do you want (ns)? (Default is 7 ns)",Tmegte
1010   Pre_gate$=VAL$(Tmegte)
1020   IF Frange=1 THEN 1120
1030   IF Frange=2 THEN 1080
1040   Fmin=6
1050   Fmax=18
1060   D$="E6GT018"
1070   GOTO 1150
1080   Fmin=8
1090   Fmax=12.4
1100   D$="E08T012P4"
[illegible]
[illegible]
1120   Fmin=2
1130   Fmax=18
1140   D$="E02T018"
1150   CALL Clear_crt
1160   PRINT "The data you have selected is:"
[illegible]  PRINT ""
[illegible]  PRINT ""
```

```
1190  PRINT "                 Start frequency is  ".Fmin." GHz."
1200  PRINT "                 Stop frequency  is ".Fmax." GHz."
1210  PRINT "                 Polarization is     ".Pol$."    ."
1220  PRINT "                 The oscillator is in ".Sweep$." mode."
1230  PRINT "                 The gate width is    ".Tnegte." Nsec.
1240  PRINT "                 The averaging is      ".Aver."."
1250  PRINT ""
1260  PRINT ""
1270  PRINT "                     ARE THE CORRECT ANTENNAS INSTALLED?"
1280  Ans$="N"
1290  INPUT "Do you want to change anything?  (Enter Y, or Default is NO).".Ans$
1300  IF Ans$="Y" THEN GOTO 570
1310  !
1320  ! SEND THE INPUT INFORMATION TO THE HP 8510.
1330  !
1340  PRINT
1350  PRINT                                        PLEASE WAIT"
1360       OUTPUT @Nwa:"STAR":Fmin:"GHz:STOP":Fmax:"GHz:"
1370       OUTPUT @Nwa:"GATESPAN":Tnegte:"ns:"
1380  IF Sweep$="RAMP" THEN
1390       OUTPUT @Nwa:"RAMP:"
1400  ELSE
1410       OUTPUT @Nwa:"STEP:"
1420  END IF
1430       OUTPUT @Nwa:"ENTO:"
1440  WAIT 5
1450  !
1460  ! THE FOLLOWING LINES CALL THE HEADER AND MEASUREMENT SUBROUTINES.  THE
        DATA COMES IN 801 REAL/IMAGINARY DATA PAIRS.
1470  !
1480  Measurement$="fr"
1490  CALL Ref_hdr(Pol$.Measurement$)
1500  CALL Measure(Reference(*).Aver.Sweep$)
1510  BEEP
1520  CALL Refbkgnd_hdr(Pol$.Measurement$)
1530  CALL Measure(Bkgdr(*).Aver.Sweep$)
1540  BEEP
1550  PRINT ""
1560 Same: Bck$="N"
1570  PRINT "               Do you want to measure a seperate target background?"
1580  INPUT "Enter Y or N: default is no.".Bck$
1590  CALL Clear ...
1600  IF Bck$="       Bck$="y" THEN
1610     CAL[illegible]       _hdr
1620     CA[illegible]       re(Bkgdt(*).Aver.Sweep$)
1630     [illegible]
1640  E[illegible]
1650          [illegible]=1 TO 2
1660        FOR L=1 TO 801
1670         Bkgdt(L.*)=Bkgdr(L.*)
1680         NEXT L
1690      NEXT [illegible]
1700  END IF
1710  CALL Clear_scr
1720  CALL Target_hdr(Bck$)
1730  CALL Measure(Target(*).Aver.Sweep$)
1740  !
1750  ! THE FOLLOWING LINES SUBTRACT THE REFERENCE AND TARGET BACKGROUNDS FROM
        REFERENCE AND TARGET MEASUREMENTS, RESPECTIVELY.
1760  !
1770  PRINT "                    Please wait while the system is number crunching."
```

```
1780 No_points=801
1790 FOR I=1 TO 2
1800    FOR J=1 TO No_points
1810       Target(J.I)=Target(J.I)-Bkgdt(J.I)
1820       Referencl(J.I)=Reference(J.I)-Bkgdr(J.I)
1830    NEXT J
1840 NEXT I
1850 !
1860 !THE FOLLOWING LINES CALCULATE (Target-Bkgnd)/(Reference-Bkgnd).
1870 !
1880 FOR L=1 TO No_points
1890   Den=Referencl(L.1)^2+Referencl(L.2)^2
1900   Cal_tgt(L.1)=(Target(L.1)*Referencl(L.1)+Target(L.2)*Referencl(L.2))/Den
1910   Cal_tgt(L.2)=(Target(L.2)*Referencl(L.1)-Target(L.1)*Referencl(L.2))/Den
1920 NEXT L
1930 !
1940 !THE FOLLOWING LINES READ IN THE EXACT SOLUTION FOR THE 5 INCH SPHERE.
1950 !
1960 IF E_data(1)<>0 THEN 2070
1970      ASSIGN @Dt TO Dfs
1980      ENTER @Dt:E_data(*)
1990      ASSIGN @Dt TO *
2000 FOR I=1 TO No_points
2010    Ex_sphere(I.1)=E_data(I)
2020    Ex_sphere(I.2)=E_data(I+No_points)
2030 NEXT I
2040 !
2050 !THE NEXT LINES CALCULATE (exact_sphere*sub_fields)
2060 !
2070 FOR K=1 TO No_points
2080   Cal_tgt2(K.1)=Cal_tgt(K.1)*Ex_sphere(K.1)-Cal_tgt(K.2)*Ex_sphere(K.2)
2090   Cal_tgt2(K.2)=Cal_tgt(K.1)*Ex_sphere(K.2)+Cal_tgt(K.2)*Ex_sphere(K.1)
2100 NEXT K
2110 !
2120 !SEND ANSWER TO THE HP 8510.  CE=(Target-Bkgdt)/(Reference-Bkgdr)
2130 !
2140      OUTPUT @Nwa:"FORM3:OUTPDATA"
2150      ENTER @Nwa_data:Preamble.Size.Bkgtr(*)
2160      OUTPUT @Nwa:"AVEROFF:GATEOFF"
2170 Sn=1
2180      OUTPUT @Nwa:"HOLD:"
2190      OUTPUT @Nwa:"FORM3:INPURAW1"
2200      OUTPUT @Nwa_data:Preamble.Size.Cal_tgt2(*)
2210 BEEP
2220 CALL Cr_menu(Fmin.Fmax.Pol.Cal_tgt2(*).Date$.Pre_gate$.Return)
2230 IF Return=1 THEN GOTO New
2240 IF Return=2 THEN GOTO Same
2250 CALL Clear_crt
2260 SUBEND
2270 !
2280 ! THIS SUBROUTINE IS A HEADER FOR BOTH THE FREQUENCY RESPONSE AND PATTERN
       CUT REFERENCE TARGET BACKGROUND MEASUREMENTS.
2290 !
2300  SUB Refbkgnd_hdr(Pol$.Measurement$)
2310 CALL Clear_crt
2320 IF Measurement$="Fr" THEN
2330      PRINT "                  The sphere measurement is complete."
2340      PRINT "              Get ready to measure the sphere background."
2350      PRINT ""
2360      PRINT ""
2370 ELSE
```

```
2380        PRINT "                         Put out the sphere background."
2390        PRINT ""
2400        PRINT "         Are the antennas aligned for ";Pol$;" polarization?"
2410        PRINT ""
2420        PRINT ""
2430   END IF
2440   PRINT "                   Hit CONTINUE when you are ready."
2450   PAUSE
2460   CALL Clear_crt
2470   PRINT ""
2480   PRINT ""
2490   PRINT "                      ";CHR$(130);"Measuring ";CHR$(128);"the sphere ba
ckground."
2500   SUBEND
2510   !
2520   ! THIS SUBROUTINE PERFORMS ALL THE FREQUENCY RESPONSE MEASUREMENTS.  THE
         SET-UP OF THE CHAMBER IS PASSED VIA THE ARRAY CALLED 'Data(*)'.
2530   !
2540   SUB Measure(Data(*),Aver,Sweep$)
2550   OPTION BASE 1
2560   INTEGER Preamble,Size
2570        ASSIGN @Nwa TO 716
2580        ASSIGN @Nwa_data TO 716:FORMAT OFF
2590        OUTPUT @Nwa;"AVERON;",Aver
2600   IF Sweep$="RAMP" THEN OUTPUT @Nwa;"NUMG;",Aver+1
2610        OUTPUT @Nwa;"FORM3;OUTPDATA"
2620        ENTER @Nwa_data;Preamble,Size,Data(*)
2630        OUTPUT @Nwa;"AVEROFF;"
2640   CALL Clear_crt
2650   SUBEND
2660   !
2670   ! THIS SUBROUTINE IS A HEADER FOR THE FREQUENCY RESPONSE TARGET
         MEASUREMENT.
2680   !
2690   SUB Target_hdr(Bck$)
2700   CALL Clear_crt
2710   IF Bck$="N" OR Bck$="" THEN GOTO 2740
2720   PRINT "                   The target background measurement is complete."
2730   PRINT ""
2740   PRINT "                            Get ready to measure the target."
2750   PRINT "                              Press CONTINUE when ready."
2760   PAUSE
2770   CALL Clear_crt
2780   PRINT ""
2790   PRINT ""
2800   PRINT "                            ";CHR$(130);"Measuring ";CHR$(128);"t
he target."
2810   SUBEND
2820   !
2830   ! THIS SUBROUTINE IS A HEADER FOR BOTH THE FREQUENCY RESPONSE AND PATTERN
         [illegible] TARGET BACKGROUND MEASUREMENT OPTIONS.
2840   !
2850   SUB [illegible]
2860   PRINT "                   Hit CONTINUE when the target background is set."
2870   PAUSE
2880   CALL Clear_crt
2890   PRINT ""
2900   PRINT "                      ";CHR$(130);"Measuring ";CHR$(128);"the targe
t background."
2910   SUBEND
2920   !
```

```
2930  ' THIS SUBROUTINE IS A MENU PRESENTED AFTER THE FREQUENCY RESPONSE IS
        COMPLETE.
2940  '
2950  SUB Fr_menu(Fmin,Fmax,Pol,Cal_tgt2(*),Date$,Pre_gate$,Return)
2960  OPTION BASE 1
2970  ASSIGN @Nwa TO 716
2980  ASSIGN @Nwa_data TO 716;FORMAT OFF
2990  DIM S_data(1605)
3000  CALL Clear_crt
3010  Dm=1
3020 Menu: PRINT "Please select an option from the menu."
3030  PRINT ""
3040  PRINT ""
3050  PRINT ""
3060  PRINT "      K0 - View the other domain."
3070  PRINT ""
3080  PRINT "         K2 - Store the frequency response data."
3090  PRINT ""
3100  PRINT "            K4 - Continue frequency response with a new target."
3110  PRINT ""
3120  PRINT "          K6 - Completely new frequency response."
3130  PRINT ""
3140  PRINT "      K8 - Back to the main menu."
3150  PRINT ""
3160  PRINT ""
3170  ON KEY 0 LABEL "Toggle Domain" GOTO C_td
3180  ON KEY 2 LABEL "Store Data" GOTO C_store
3190  ON KEY 4 LABEL "New Target " GOTO C_same
3200  ON KEY 6 LABEL "New Freq Resp" GOTO C_new
3210  ON KEY 8 LABEL "Main Menu" GOTO C_strt
3220  ON KEY 1 GOTO Again
3230  ON KEY 3 GOTO Again
3240  ON KEY 5 GOTO Again
3250  ON KEY 7 GOTO Again
3260  ON KEY 9 GOTO Again
3270 Again:DISP "Please hit the appropriate soft key."
3280  GOTO Again
3290 C_td: OFF KEY
3300  Dm=-1*Dm
3310       IF Dm=1 THEN OUTPUT @Nwa;"FREQ;"
3320       IF Dm=-1 THEN OUTPUT @Nwa;"TIMB;LOGM;"
3330  CALL Clear_crt
3340  GOTO Menu
3350 C_same: OFF KEY
3350  Return=2
3370  CALL Clear_crt
3380  CALL Check(Chk$)
3390  IF Chk$="Y" THEN GOTO C_store
3400       IF Dm=-1 THEN OUTPUT @Nwa;"FREQ;"
3410       OUTPUT @Nwa;"CONT;GATEON;"
3420  [illegible]
3430  SUBEXIT
3440 C_[illegible]: OFF KEY
3450  [illegible]Clear_crt
3460    [illegible]
3470       S_data(I)=Cal_tgt2(I,1)
3480       S_data(I+[illegible])=Cal_tgt2(I,2)
3490    NEXT I
3500       S_data([illegible])=Fmin
3510       S_data([illegible])=Fmax
3520       S_data([illegible])=Pol
```

```
3530  CALL Store(S_data(*),Date$,Pre_gate$)
3540  CALL Clear_crt
3550  GOTO Menu
3560 C_new: OFF KEY
3570  Return=1
3580  CALL Clear_crt
3590  CALL Check(Chk$)
3600  IF Chk$="Y" THEN GOTO C_store
3610        IF Dm=-1 THEN OUTPUT @Nwa:"FREQ:"
3620        OUTPUT @Nwa:"CONT:GATEON:"
3630  WAIT 5
3640  SUBEXIT
3650 C_strt: OFF KEY
3660  Return=0
3670  CALL Clear_crt
3680  CALL Check(Chk$)
3690  IF Chk$="Y" THEN GOTO C_store
3700        OUTPUT @Nwa:"RECA8:"
3710  SUBEND
3720  !
3730  ! THIS SUBROUTINE STORES A FREQUENCY SWEEP FILE.
3740  !
3750  SUB Store(S_data(*),Date$,Pre_gate$)
3760  OPTION BASE 1
3770  CALL Clear_crt
3780  PRINT ""
3790  PRINT ""
3800  PRINT ""
3810  PRINT ""
3820  PRINT "       Insert storage disk into the right-hand disk drive."
3830  PRINT ""
3840  PRINT "             Press   ";CHR$(129);"CONTINUE";CHR$(128);"    when yo
u are ready."
3850  PAUSE
3860  CALL Clear_crt
3870 Name:PRINT "The file name must have at least one UPPER CASE letter."
3880  PRINT ""
3890  INPUT "  Enter the file name for the current set of data.",Dt_file1$
3900  File_name1$=LWC$(Dt_file1$)
3910 Disk: CREATE BDAT Dt_file1$,1,12904
3920        ASSIGN @Dt_file1 TO Dt_file1$
3930        OUTPUT @Dt_file1:S_data(*)
3940        ASSIGN @Dt_file1 TO *
3950        CREATE BDAT File_name1$,2,30
3960        ASSIGN @File_name1 TO File_name1$
3970        OUTPUT @File_name1,1;Date$
3980        OUTPUT @File_name1,2;Pre_gate$
3990        ASSIGN @File_name TO *
4000  SUBEND
4010  !
4020  ! THIS SUBROUTINE IS THE MAIN MENU FOR THE PATTERN CUT.
4030  !
4040  SUB Pc(Date$)
4050  OPTION BASE 1
4060  DIM A(2),Pcbkgdt(365,2),Pcreference(365,2),Plot_dt(365),Pcplot(370)
4070  DIM View(365),View1(365),Ptrace_data(365),Pdata(365)
4080  ASSIGN @Nwa TO 716
4090  ASSIGN @Nwa_data1 TO 716;FORMAT OFF
4100  INTEGER Preamble,Size,3
4110 New: CALL Clear_crt
4120  PRINT "At present, only the 360 degree option is active."
```

```
4130  PRINT "Input the parameters for the pattern cut."
4140  PRINT ""
4150  PRINT ""
4160  INPUT "      Operating frequency? (Between 2 and 18 GHz)",Freq
4170  IF Freq<2 OR Freq>18 THEN GOTO 4160
4180  CALL Clear_crt
4190  INPUT "What gate do you want (ns)? (Default is 7 ns)",Tmegte
4200  IF Tmegte=0 THEN Tmegte=7
4210  Pre_gate$=VAL$(Tmegte)
4220  Pol$=""
4230  INPUT "      Polarization? (Enter V or H: Default is horizontal)",Pol$
4240  IF Pol$<>"" AND Pol$<>"H" AND Pol$<>"V" THEN GOTO 4230
4250  IF Pol$="H" OR Pol$="" THEN
4260     Pol$="HORIZONTAL"
4270     Pol=0
4280  ELSE
4290     Pol$="VERTICAL"
4300     Pol=1
4310  END IF
4320  CALL Clear_crt
4330  Speed=0
4340  PRINT "                     What is the rotation speed of the target?"
4350  PRINT "                              (Default is 1.5)"
4360  PRINT ""
4370  PRINT "                   SLOWEST              FASTEST"
4380  PRINT "                           --------->"
4390  PRINT "                     1.5                  0.1"
4400  INPUT Speed
4410  IF Speed=0 THEN Speed=1.5
4420  IF Speed<.1 OR Speed>1.5 THEN GOTO 4400
4430  CALL Clear_crt
4440  Angle1=0
4450  Angle2=360
4460  Resolution=1
4470  !INPUT "      Starting aspect angle?",Angle1
4480  CALL Clear_crt
4490  !INPUT "      Ending aspect angle?",Angle2
4500  CALL Clear_crt
4510  !INPUT "      Angular resolution? (Default is 1 degree)",Resolution
4520  IF Resoition=0 THEN Resolution=1
4530  CALL Clear_crt
4540  PRINT "You have input the following parameters."
4550  PRINT ""
4560  PRINT ""
4570  PRINT "     Operating frequency .....",Freq,"GHz."
4580  PRINT "     Gate width ..............",Tmegte,"nsec."
4590  PRINT "     Polarization ............","",Pol$,"."
4600  PRINT "     Starting aspect angle ...",Angle1,"degrees."
4610  PRINT "     Ending aspect angle .....",Angle2,"degrees."
4620  PRINT "     Angular resolution ..... ",Resolution,"degree."
4630  PRINT "     Target rotation rate ....",Speed
4640  PRINT ""
4650  PRINT ""
4660  Ans$=""
4670  INPUT "Do you want to change anything? (Enter Y or N: Default is no)",Ans$
4680  IF Ans$<>"" AND Ans$<>"Y" AND Ans$<>"N" THEN GOTO 4670
4690  IF Ans$="Y" THEN GOTO 4110
4700  !
4710  !THE FOLLOWING LINES SEND THE INPUT INFORMATION TO THE HP 8510.
4720  !
4730        OUTPUT @Nwa;"MARK1";Freq;"GHz;"
```

```
4740       OUTPUT @Nwa;"GATESPAN";Imegte;"ns;"
4750       OUTPUT @Nwa;"EMTO;"
4760 No_degs=Angle2-Angle1
4770 No_incrmts=No_degs/Resolution
4780 PRINT "                        PLEASE WAIT"
4790 WAIT 3
4800 !
4810 !THE NEXT SECTION CALLS THE HEADER AND MEASUREMENT SUBROUTINES.
4820 !
4830 Measurement$="PC"
4840 CALL Refbkgnd_hdr(Pol$,Measurement$)
4850 Rep$=""
4860 CALL Background_meas(Rep$)
4870 CALL Ref_hdr(Pol$,Measurement$)
4880 CALL Ref_meas(Sphamp)
4890 !
4900 !ASK IF THERE IS A DIFFERENT TARGET BACKGROUND
4910 !
4920 PRINT "            Do you need a separate target background?"
4930 PRINT ""
4940 Rep$=""
4950 INPUT "Enter Y or N (Default is no).",Rep$
4960 IF Rep$="N" OR Rep$="" THEN GOTO 5010
4970 IF Rep$<>"Y" THEN GOTO 4950
4980 CALL Clear_crt
4990 CALL Tgtbkgnd_hdr
5000 CALL Background_meas(Rep$)
5010 CALL Tgt_hdr
5020 CALL Tgt_meas(Pdata(*),No_incrmts,Speed)
5030 !
5040 ! THE FOLLOWING LINES CALCULATE THE RCS OF THE TARGET.
5050 !
5060 ! Plot_dt(J) ...... RCS of the target (dBsm)
5070 ! Rcs ............. exact RCS of the 5 inch sphere (dBsm)
5080 ! Pdata(J) ........ target - target background (dBsm)
5090 ! Sphamp .......... reference target - reference target background (dBsm)
5100 !
5110 Diam=5
5120 Rcs=10*LGT(PI*(Diam*.0254/2)^2)
5130 FOR J=1 TO 360
5140     Plot_dt(J)=Rcs+Pdata(J)-Sphamp
5150     NEXT J
5160 !
5170 ! THIS SUBROUTINE DISPLAYS THE PATTERN CUT ON THE CRT.
5180 !
5190 CALL Show_crt(Freq,Pol,Date$,Pre_gate$,Choice,Plot_dt(*))
5200 IF Choice=1 THEN GOTO New
5210 CALL Clear_crt
5220 SUBEND
5230 !
5240 ! THIS SUBROUTINE CLEARS THE CRT.
5250 !
5260 SUB Clear_crt
5270   OUTPUT KBD;" K";
5280 SUBEND
5290 !
5300 ! THIS SUBROUTINE PERFORMS THE PATTERN CUT TARGET MEASUREMENT.
5310 !
5320 SUB Tgt_meas(Pdata(*),No_incrmts,Speed)
5330 OPTION BASE 1
5340      ASSIGN @Nwa TO 716
```

```
5350        ASSIGN @Nwa_data1 TO 716:FORMAT OFF
5360        OUTPUT 709 USING "K";"V44.0"
5370        OUTPUT 709 USING "K";"S41.0"
5380        OUTPUT 709 USING "K";"C40.0"
5390   PRINT "                              ";CHR$(130);"MEASURING";CHR$(128);" the target
.."
5400   FOR I=1 TO 360
5410        OUTPUT @Nwa;"OUTPMARK;"
5420        ENTER @Nwa;Pdata(I),B
5430        OUTPUT 709 USING "K";"I4"
5440        WAIT Speed
5450   NEXT I
5460   CALL Clear_crt
5470   BEEP
5480   SUBEND
5490   !
5500   ! THIS SUBROUTINE IS A HEADER FOR THE PATTERN CUT TARGET MEASUREMENT.
5510   !
5520   SUB Tgt_hdr
5530   CALL Clear_crt
5540   PRINT "                        Get ready to measure the target."
5550   PRINT ""
5560   PRINT "                Has the controller been assigned to the HP 8510?"
5570   PRINT "                        (Enter 'QUIT 2' on the handheld)"
5580   PRINT ""
5590   PRINT ""
5600   PRINT ""
5610   PRINT "                    Hit CONTINUE when the target is in place."
5620   PAUSE
5630   CALL Clear_crt
5640   SUBEND
5650   !
5660   ! THIS SUBROUTINE PERFORMS THE PATTERN CUT REFERENCE AND TARGET BACKGROUND
          MEASUREMENTS.
5670   !
5680   SUB Background_meas(Rep$)
5690        ASSIGN @Nwa TO 716
5700        OUTPUT @Nwa;"DISPDATA;AVERON32;"
5710   WAIT 6
5720        OUTPUT @Nwa;"DATI;MINU;DISPMATH;AVEROFF;"
5730   BEEP
5740   SUBEND
5750   !
5760   !THIS SUBROUTINE PERFORMS THE PATTERN CUT REFERENCE TARGET MEASUREMENT.
5770   !
5780   SUB Ref_meas(Sphamp)
5790   ASSIGN @Nwa TO 716
5800   OPTION BASE 1
5810        OUTPUT @Nwa;"AVERON32;"
5820   WAIT 6
5830        OUTPUT @Nwa;"OUTPMARK;AVEROFF;"
5840        ENTER @Nwa;Sphamp,B
5850   BEEP
5860   CALL Clear_crt
5870   SUBEND
5880   !
5890   ! THIS SUBROUTINE IS A HEADER FOR BOTH THE FREQUENCY RESPONSE AND PATTERN
         CUT REFERENCE TARGET MEASUREMENTS.
5900   !
5910   SUB Ref_hdr(Pol$,Measurement$)
5920   CALL Clear_crt
```

```
5930  IF Measurement$="PC" THEN GOTO 5970
5940  PRINT "   Are the antennas aligned for";Pol$;"    polarization?"
5950  PRINT ""
5960  PRINT ""
5970  PRINT "                          Put out the reference target."
5980  PRINT "                         Hit CONTINUE when you are ready."
5990  PAUSE
6000  CALL Clear_crt
6010  PRINT "                              ";CHR$(130);"Measuring ";CHR$(128);" the sp
here."
6020  SUBEND
6030  !
6040  ! THIS SUBROUTINE STORES A PATTERN CUT FILE.
6050  !
6060  SUB Stre(Date$,Pre_gate$,View(*))
6070  OPTION BASE 1
6080  CALL Clear_crt
6090  PRINT ""
6100  PRINT ""
6110  PRINT ""
6120  PRINT ""
6130  PRINT "        Insert storage disk into the right-hand disk drive."
6140  PRINT ""
6150  PRINT "                 Press   ";CHR$(129);"CONTINUE";CHR$(129);"    when yo
u are ready."
6160  PAUSE
6170  CALL Clear_crt
6180 Name:PRINT "The file name must have at least one UPPER CASE letter."
6190  PRINT ""
6200  INPUT "  Enter the file name for the current set of data.",Dt_file2$
6210  File_name2$=LWC$(Dt_file2$)
6220 Disk: CREATE BDAT Dt_file2$,1,2960
6230        ASSIGN @Dt_file2 TO Dt_file2$
6240        OUTPUT @Dt_file2;View(*)
6250        ASSIGN @Dt_file2 TO *
6260        CREATE BDAT File_name2$,2,30
6270        ASSIGN @File_name2 TO File_name2$
6280        OUTPUT @File_name2,1;Date$
6290        OUTPUT @File_name2,2;Pre_gate$
6300        ASSIGN @File_name TO *
6310  CALL Clear_crt
6320  SUBEND
6330  !
6340  ! THIS SUBROUTINE MAKES SURE THE USER HAS REMEMBERED TO SAVE THE DATA.
6350  !
6360  SUB Check(Chk$)
6370  PRINT ""
6380  PRINT ""
6390  PRINT ""
6400  PRINT ""
6410  PRINT "      Have you saved your data?  It will be lost if you haven't."
6420  PRINT ""
6430  Chk$=""
6440  INPUT "DO YOU WANT TO SAVE DATA? (Enter  Y  or  N    Default is no)",Chk$
6450  CALL Clear_crt
6460  SUBEND
6470  !
6480  !THIS SUBROUTINE DISPLAYS THE PATTERN CUT ON THE CRT.
6490  !
6500  SUB Show_crt(Freq,Pol,Date$,Pre_gate$,Choice,View(*))
6510 Start:   CALL Clear_crt
```

```
6520      GINIT
6530      PLOTTER IS 3,"INTERNAL"
6540      Ymin=View(1)
6550      Ymax=Ymin
6560      FOR I=1 TO 361
6570        IF View(I)<Ymin THEN Ymin=View(I)
6580        IF View(I)>Ymax THEN Ymax=View(I)
6590      NEXT I
6600      Ymax=Ymax+10
6610      Ymax=PROUND(Ymax,1)
6620      Ymin=Ymin-10
6630      Ymin=PROUND(Ymin,1)
6640      Range=Ymax-Ymin
6650      GRAPHICS ON
6660      MOVE 0,95
6670      CSIZE 3
6680      LABEL Name$
6690      CSIZE 6
6700      LORG 6
6710      FOR I=-.3 TO .3 STEP .1
6720        MOVE 70+I,100
6730        LABEL "LOW OBSERVABLES"
6740      NEXT I
6750      LORG 1
6760      CSIZE 4
6770      MOVE 0,62
6780      Label$="RCS"
6790      FOR I=1 TO 3
6800        LABEL Label$[I,I]
6810      NEXT I
6820      MOVE 56,15
6830      LABEL "ASPECT ANGLE"
6840      VIEWPORT 15,125,30,90
6850      FRAME
6860      WINDOW 0,360,Ymin,Ymax
6870      AXES 5,2,0,Ymin,9,5,2
6880      CSIZE 3
6890      LORG 6
6900      CLIP OFF
6910      FOR I=0 TO 360 STEP 45
6920        MOVE I,Ymin-1
6930        LABEL I
6940      NEXT I
6950      LORG 8
6960      FOR I=Ymin TO Ymax STEP 10
6970        MOVE -1,I
6980        LABEL I
6990      NEXT I
7000      FOR I=0 TO 359
7010        PLOT I,View(I+1)
7020      NEXT I
7030      ON KEY 0 LABEL "SHIFT DATA" GOTO Shift
7040      ON KEY 1 GOTO Idle
7050      ON KEY 2 LABEL "STORE THE PC" GOTO C_store
7060      ON KEY 3 GOTO Idle
7070      ON KEY 4 LABEL "NEW PC" GOTO C_new
7080      ON KEY 5 LABEL "DUMP TO PRNTR" GOTO Dump
7090      ON KEY 6 GOTO Idle
7100      ON KEY 7 GOTO Idle
7110      ON KEY 8 GOTO Idle
7120      ON KEY 9 LABEL "MAIN MENU" GOTO C_start
```

```
7130      !ON KBD GOTO Bottom
7140 Idle:DISP CHR$(131);"";CHR$(128);"";TIME$(TIMEDATE)
7150      WAIT 1
7160      GOTO Idle
7170 Dump:PRINTER IS 701
7180      OUTPUT KBD:" N":
7190      PRINTER IS CRT
7200      GOTO Idle
7210 Shifft: OFF KEY
7220      GRAPHICS OFF
7230      CALL Clear_crt
7240      DIM View2(361),Plot_dt(365)
7250      INPUT "How many degrees should the data be shifted? (- for shift left)",
Shft
7260      IF Shft<-360 OR Shft>360 THEN GOTO 7250
7270      IF Shft>0 THEN
7280         Shft=360-Shft
7290      ELSE
7300         Shft=Shft*(-1)
7310      END IF
7320      FOR I=1 TO 360-Shft
7330          View2(I)=View(I+Shft)
7340          NEXT I
7350      FOR I2=1 TO Shft
7360          View2(360-Shft+I2)=View(I2)
7370          NEXT I2
7380      FOR I3=1 TO 360
7390          Plot_dt(I3)=View2(I3)
7400          View(I3)=View2(I3)
7410          NEXT I3
7420      GOTO Start
7430 C_stre:  OFF KEY
7440      CALL Clear_crt
7450      GRAPHICS OFF
7460        View(361)=Freq
7470        View(362)=Pol
7480      CALL Stre(Date$,Pre_gate$,View(*))
7490      CALL Clear_crt
7500      GOTO Start
7510 C_new:  OFF KEY
7520      GRAPHICS OFF
7530      CALL Clear_crt
7540      Choice=1
7550      CALL Check(Chk$)
7560      IF Chk$="Y" THEN GOTO C_stre
7570      SUBEXIT
7580 C_strt:  GRAPHICS OFF
7590      CALL Clear_crt
7600      Choice=0
7610      CALL Check(Chk$)
7620      IF Chk$="Y" THEN GOTO C_stre
7630      SUBEXIT
7640 Bottom:GRAPHICS OFF
7650      CALL Clear_crt
7660  SUBEND
7670  !
7680  !
7690  SUB Proc_choice
7700  ! written by Dana J. Bergey, May 1989
7710  CALL Clr_scr
7720 Choice: PRINT
```

```
7730  PRINT
7740  PRINT
7750  PRINT "                  WHAT TYPE OF FILE DO YOU WISH TO PROCESS ?"
7760  PRINT "                     FREQUENCY/TIME DATA  OR  PATTERN DATA"
7770  ON KEY 0 LABEL "FREQ/TIM" GOTO Freqtim
7780  ON KEY 1 GOTO Idle
7790  ON KEY 2 LABEL "PATTERN" GOTO Pattern
7800  ON KEY 3 GOTO Idle
7810  ON KEY 4 GOTO Idle
7820  ON KEY 5 GOTO Idle
7830  ON KEY 6 GOTO Idle
7840  ON KEY 7 GOTO Idle
7850  ON KEY 8 GOTO Idle
7860  ON KEY 9 LABEL "EXIT" GOTO Exit
7870 Idle: DISP "        PRESS APPROPRIATE SOFT KEY"
7880  GOTO Idle
7890 Freqtim:  CALL Clr_scr
7900  PRINT "                    Please ";CHR$(130);"wait";CHR$(128);" while the syste
m is being configured."
7910  OFF KEY
7920  CALL Procplot
7930  GOTO Choice
7940 Pattern:   CALL Clr_scr
7950  OFF KEY
7960  CALL Pat_procplot
7970  GOTO Choice
7980 Exit:   CALL Clr_scr
7990  OFF KEY
8000  SUBEND
8010  !
8020  !
8030  SUB Procplot
8040  ! Written by Dana J. Bergey, May 1989
8050  OPTION BASE 1
8060  ASSIGN @Nwa TO 716
8070  ASSIGN @Nwa_data TO 716;FORMAT OFF
8080  DIM Trace_data(801,2),Plot_dt(801),Data(801,2)
8090  OUTPUT @Nwa;"RECA8;POIN801;"
8100  WAIT 11
8110  CALL Clear_crt
8120 Input: CALL Input(Trace_data(*),Date$,File_name$,Fr1,Fr2,Polarity,Pre_gate$
)
8130  CALL Present_data(Fr1,Fr2,Trace_data(*))
8140  OUTPUT @Nwa;"GATECENT 0;ENTO;"
8150  Dm=1
8160  Gate=-1
8170  CALL Clear_crt
8180 Menu:  PRINT
8190  PRINT
8200  PRINT "*************************************************************
*******"
8210  PRINT
8220  PRINT
8230  PRINT
8240  PRINT
8250  IF Dm=1 THEN
8260    PRINT "          ";CHR$(129);"YOU ARE NOW VIEWING THE FREQUENCY DOMAIN";C
HR$(128)
8270    ON KEY 0 LABEL "TIME DOMAIN" GOTO Domain
8280    ON KEY 5 LABEL "  NEW DATA" GOTO New_data
8290  ELSE
```

```
8300      PRINT "          ":CHR$(129):"YOU ARE NOW VIEWING THE TIME DOMAIN":CHR$(1
28)
8310      ON KEY 0 LABEL "FREQ. DOMAIN" GOTO Domain
8320      ON KEY 5 LABEL "SPECIFY GATE" GOTO Gate
8330   END IF
8340   PRINT
8350   PRINT
8360   IF Gate=1 THEN PRINT "          ":CHR$(129):"A TIME GATE HAS BEEN APPLIED TO
 THE DATA":CHR$(128)
8370   ON KEY 2 LABEL "   PLOT" GOTO Plot
8380   ON KEY 3 GOTO Idle
8390   ON KEY 9 LABEL "   EXIT" GOTO Exit
8400   ON KEY 1 GOTO Idle
8410   ON KEY 4 GOTO Idle
8420   ON KEY 6 GOTO Idle
8430   ON KEY 7 GOTO Idle
8440   ON KEY 8 GOTO Idle
8450 Idle:  DISP "ENTER APPROPRIATE SOFT KEY."
8460   GOTO Idle
8470 Domain:  Dm=-1*Dm
8480   IF Dm=1 THEN
8490      OUTPUT @Nwa:"FREQ:"
8500   ELSE
8510      OUTPUT @Nwa:"TIMB:LOGM:"
8520      WAIT 2
8530   END IF
8540   CALL Clr_scr
8550   GOTO Menu
8560 New_data:  CALL Clr_scr
8570   OFF KEY
8580   OUTPUT @Nwa:"FREQ:CONT:GATEOFF:"
8590   GOTO Input
8600 Exit:  CALL Clr_scr
8610   OFF KEY
8620   OUTPUT @Nwa:"RECA8:POIN801:"
8630   SUBEXIT
8640 Gate:  CALL Clr_scr
8650   ON KEY 5 LABEL "ACTIVATE GATE" GOTO Onoff
8660   ON KEY 7 LABEL "  CENTER" GOTO Center
8670   ON KEY 9 LABEL "   SPAN " GOTO Span
8680   ON KEY 0 GOTO Idle2
8690   ON KEY 1 GOTO Idle2
8700   ON KEY 2 GOTO Idle2
8710   ON KEY 3 GOTO Idle2
8720   ON KEY 4 GOTO Idle2
8730   ON KEY 6 GOTO Idle2
8740   ON KEY 8 GOTO Idle2
8750 Idle2:  DISP "ENTER APPROPRIATE SOFT KEY"
8760   GOTO Idle2
8770 Onoff:  CALL Clr_scr
8780         Gate=-1*Gate
8790   IF Gate=1 THEN OUTPUT @Nwa:"GATEON:"
8800   IF Gate=-1 THEN OUTPUT @Nwa:"GATEOFF:"
8810   GOTO Menu
8820 Center:  CALL Clr_scr
8830   IF Dm=1 THEN OUTPUT @Nwa:"TIME:LOGM:"
8840   Dm=-1
8850   IF Gate=1 THEN OUTPUT @Nwa:"GATEOFF:"
8860   Gate=-1
8870   OUTPUT @Nwa:"GATECENT:"
8880   LOCAL 716
```

```
8890  PRINT
8900  PRINT
8910  PRINT
8920  PRINT "     USE KNOB ON 8510 TO CENTER GATE.  THEN PRESS CONTINUE."
8930  PAUSE
8940  OUTPUT @Nwa;"ENTO;"
8950  GOTO Gate
8960 Span:  CALL Clr_scr
8970  IF Dm=1 THEN OUTPUT @Nwa:"TIMB;LOGM;"
8980  Dm=-1
8990  IF Gate=1 THEN OUTPUT @Nwa:"      F;"
9000  Gate=-1
9010  OUTPUT @Nwa:"GATESPAN;"
9020  LOCAL 716
9030  PRINT
9040  PRINT
9050  PRINT
9060  PRINT "     USE KNOB ON 8510 TO SET GATE SPAN.  THEN PRESS CONTINUE."
9070  PAUSE
9080  OUTPUT @Nwa:"ENTO;"
9090  GOTO Gate
9100 Plot:  CALL Clr_scr
9110        PRINT "                                    Please ";CHRS(130);"wait";CHRS
(128);
9120   OFF KEY
9130   ASSIGN @Nwa_data2 TO 716;FORMAT ON
9140   OUTPUT @Nwa:"FORM4;OUTPFORM;"
9150   ENTER @Nwa_data2;Data(*)
9160   FOR I=1 TO 801
9170   Plot_dt(I)=Data(I,1)
9180   NEXT I
9190   IF Gate=1 THEN
9200     OUTPUT @Nwa:"GATECENT;OUTPACTI;"
9210     ENTER @Nwa_data2;Gate_cent
9220     OUTPUT @Nwa:"GATESPAN;OUTPACTI;"
9230     ENTER @Nwa_data2;Gate_span
9240     OUTPUT @Nwa;"ENTO;"
9250   ELSE
9260     Gate_span=0
9270   END IF
9280   Gate_cent=Gate_cent*10^9
9290   Gate_span=Gate_span*10^9
9300   IF Fr1=2 THEN Bandwidth$="2-18 GHz"
9310   IF Fr1=6 THEN Bandwidth$="6-1
9320   IF Fr1=9 THEN Bandwidth$="8-1
9330 Plotmenu:  CALL Clr_scr
9340    =-5
9350   I=5
9360  ON KEY 5 LABEL "PLOT                     lot_grid
9370  ON KEY 7 LABEL "P                       Plot_data
9380  ON KEY 9 LABEL "EXIT"         Plot_exit
9390  ON KEY 0 GOTO Idle3
9400  ON KEY 1 LABEL "LINE TYPE" GOTO Lin_typ
9410  ON KEY 2 GOTO Idle3
9420  ON KEY 3 GOTO Idle3
9430  ON KEY 4 GOTO Idle3
9440  ON KEY 6 GOTO Idle3
9450  ON KEY 8 GOTO Idle3
9460 Idle3:  DISP "ENTER APPROPRIATE SOFT KEY"
9470  GOTO Idle3
9480 Lin_typ:  CALL Clr_scr
```

```
9490  PRINT "          LINE TYPE          DESCRIPTION"
9500  PRINT ""
9510  PRINT "             0      -     Solid line"
9520  PRINT ""
9530  PRINT "             1      -     Short dashed line"
9540  PRINT ""
9550  PRINT "          2 to 6    -     Progressively longer dashes"
9560  ON KEY 0 LABEL "0" GOTO Zero
9570  ON KEY 1 LABEL "1" GOTO One
9580  ON KEY 2 LABEL "2" GOTO Two
9590  ON KEY 3 LABEL "3" GOTO Three
9600  ON KEY 4 LABEL "4" GOTO Four
9610  ON KEY 5 LABEL "5" GOTO Five
9620  ON KEY 6 LABEL "6" GOTO Six
9630  ON KEY 7 GOTO Lidle
9640  ON KEY 8 GOTO Lidle
9650  ON KEY 9 GOTO Lidle
9660 Lidle:  DISP "SELECT LINE TYPE"
9670  GOTO Lidle
9680 Zero: Lin_typ=0
9690  GOTO Plotmenu
9700 One: Lin_typ=1
9710  GOTO Plotmenu
9720 Two: Lin_typ=2
9730  GOTO Plotmenu
9740 Three: Lin_typ=3
9750  GOTO Plotmenu
9760 Four: Lin_typ=4
9770  GOTO Plotmenu
9780 Five: Lin_typ=5
9790  GOTO Plotmenu
9800 Six: Lin_typ=6
9810  GOTO Plotmenu
9820 Plot_grid:  CALL Clr_scr
9830  OFF KEY
9840  CALL Scale_cn(Ymax,Ymin,Plot_dt(*))
9850  CALL Clr_scr
9860  IF Dm=1 THEN CALL Draw_pl(Ymax,Ymin,Fr1,Fr2,Dm,Num_traces)
9870  IF Dm=-1 THEN CALL Draw_pl(Ymax,Ymin,T1,T2,Dm,Num_traces)
9880  GOTO Plotmenu
9890 Plot_data:  CALL Clr_scr
9900 PRINT "                    Please ";CHR$(130);"wait";CHR$(128);" while the da
ta is plotted."
9910  OFF KEY
9920  CALL Draw_data(Plot_dt(*),Ymax,Ymin,File_name$,Bandwidth$,F    ity,Pre_gat
e$,Gate_cent,Gate_span,Date$,Num_traces,Lin_typ)
9930  CALL Clear_crt
9940  GOTO Plotmenu
9950 Plot_exit:  CALL Clr_scr
9960   GOTO Menu
9970   SUBEND
9980   !
9990   !
10000 SUB Input(Trace_data(*),Date$,File_name$,Fr1,Fr2,F   arity,Pre_gate$)
10010 !  Written by Dana J. Bergey, May 1989
10020   OPTION BASE 1
10030   DIM Data(1605)
10040   CALL Clear_crt
10050 Start:PRINT ""
10060   PRINT ""
10070   PRINT "              Insert disc containing data f... into ... and d...
```

```
rive."
10080    PRINT ""
10090    PRINT "                          Press ";CHR$(131);"CONTINUE";CHR$(128);
" when ready."
10100    PAUSE
10110    ON ERROR GOTO Err2
10120    CALL Clear_crt
10130    INPUT "Do you wish to see listing of disk (Y or N)?  Default is NO.",Lli
st$
10140    IF Llist$="Y" THEN
10150      CAT
10160      ON KBD GOTO Again
10170      DISP CHR$(131);"Press space bar when ready.";CHR$(128)
10180 Lloop:GOTO Lloop
10190    ELSE
10200      GOTO Again
10210    END IF
10220 Again:CALL Clear_crt
10230    OFF KBD
10240    OFF ERROR
10250 Name:INPUT "Enter the file name of the stored file.",File_name$
10260    ON ERROR GOTO Err1
10270    GOTO Inbound
10280 Err1:PRINT ERRM$
10290    GOTO Name
10300 Inbound:PRINT "           Please";CHR$(130);" wait";CHR$(128);" while your
file is being loaded and processed."
10310    ASSIGN @File1 TO File_name$
10320    ENTER @File1;Data(*)
10330    ASSIGN @File1 TO *
10340    FOR I=1 TO 801
10350      Trace_data(I,1)=Data(I)
10360      Trace_data(I,2)=Data(I+801)
10370    NEXT I
10380    Fr1=Data(1603)
10390    Fr2=Data(1604)
10400    Polarity=Data(1605)
10410    Date_file$=LWC$(File_name$)
10420    ASSIGN @File2 TO Date_file$
10430    ENTER @File2,1;Date$
10440    ENTER @File2,2;Pre_gate$
10450    ASSIGN @File2 TO *
10460    SUBEXIT
10470 Err2:CALL Clear_crt
10480    DISP ERRM$
10490    BEEP
10500    OFF ERROR
10510    GOTO Start
10520 SUBEND
10530    !
10540    !
10550 SUB Present_data(Fr1,Fr2,Trace_data(*))
10560 !  Written by Dana J. Bergey, May 1989
10570    OPTION BASE 1
10580    INTEGER Preamble,Size
10590    DIM Junk(801,2)
10600    ASSIGN @Nwa TO 716
10610    ASSIGN @Nwa_data TO 716;FORMAT OFF
10620    OUTPUT @Nwa;"FORM3;OUTPDATA"
10630    ENTER @Nwa_data;Preamble,Size,Junk(*)
10640    WAIT 2
```

```
10650    OUTPUT @Nwa;"STAR";Fr1;"GHz;"
10660    WAIT 3
10670    OUTPUT @Nwa;"STOP";Fr2;"GHz;"
10680    WAIT 3
10690    Im=1
10700    OUTPUT @Nwa;"HOLD;GATEOFF;"
10710    OUTPUT @Nwa;"FORM3;INPURAW1"
10720    OUTPUT @Nwa_data;Preamble,Size,Trac...(*)
10730 SUBEND
10740 !
10750 !
10760 SUB Scale_cn(Ymax,Ymin,Plot_dt(*))
10770 !  Written by Dana J. Bergey, May 1989
10780 !OPTION BASE 1 !
10790   Ymin=Plot_dt(1)                    !    INITIALIZE
10800   Ymax=Ymin
10810     FOR J=1 TO 801
10820       IF Plot_dt(J)<Ymin THEN Ymin=Plot_dt(J)
10830       IF Plot_dt(J)>Ymax THEN Ymax=Plot_dt(J)
10840     NEXT J
10850   CALL Clear_crt
10860   PRINT "        *
*"
10870   PRINT "        *                        SCALING CHOICES
"
10880   PRINT "        *

10890   PRINT "        **************************************************
*******."
10900   PRINT ""
10910   PRINT "        The maximum value of the current data is ";Ymax;" (dBsm)."
10920   PRINT "        The minimum value of the current data is ";Ymin;" (dBsm)."
10930   PRINT ""
10940   PRINT "        ";CHR$(129);"AUTO SCALE";CHR$(128);"..........Computer gen
erates scale."
10950   PRINT ""
10960   PRINT "        ";CHR$(129);"USER";CHR$(128);"................User defines
 scale."
10970   PRINT ""
10980   PRINT "        ";CHR$(129);"MAIN MENU";CHR$(128);"...........Exit back to
main menu."
10990   ON KEY 5 LABEL "    AUTO SCALE" GOTO Auto
11000   ON KEY 7 LABEL "      USER" GOTO User
11010   ON KEY 9 LABEL "    MAIN MENU" GOTO M-
11020   ON KEY 0 GOTO Idle
11030   ON KEY 1 GOTO Idle
11040   ON KEY 2 GOTO Idle
11050   ON KEY 3 GOTO Idle
11060   ON KEY 4 GOTO Idle
11070   ON KEY 6 GOTO Idle
11080   ON KEY 8 GOTO Idle
11090 Idle:DISP "Enter appropriate soft key."
11100   GOTO Idle
11110 Mn:OFF KEY
11120   Help=1
11130   SUBEXIT
11140 User:CALL Clear_crt
11150   PRINT "        *
*"
11160   PRINT "        *                        USER DEFINED SCALE
*"
```

```
11170   PRINT "         *
*"
11180   PRINT "         ***************************************************
*******"
11190   PRINT ""
11200   PRINT ""
11210   INPUT "Enter the maximum value of RCS scale desired.",Ymax
11220   INPUT "Enter the minimum value of RCS scale desired.",Ymin
11230   Range=Ymax-Ymin
11240   IF Range>0 THEN GOTO Good_rge
11250   BEEP
11260   IF Range=0 THEN PRINT "                 You have entered the same value fo
r Ymin and Ymax."
11270   IF Range<0 THEN PRINT "                       Your Ymin is greater than y
our Ymax."
11280   PRINT ""
11290   PRINT "                                   Try again!"
11300   GOTO 11210
11310 Good_rge:CALL Clear_crt
11320   OFF KEY
11330   SUBEXIT
11340 Auto:CALL Clear_crt
11350   Ymax=Ymax+10
11360   Ymax=PROUND(Ymax,1)
11370   Ymin=Ymin-10
11380   Ymin=PROUND(Ymin,1)
11390   OFF KEY
11400 SUBEND
11410 !
11420 !
11430 SUB Heading
11440   CALL Clear_crt
11450   PRINT "         ":CHR$(129):"*******************************************
*******************":CHR$(128)
11460   PRINT "         ":CHR$(129):"*
*":CHR$(128)
11470   PRINT "         ":CHR$(129):"*        AFIT'S AUTOMATED SCATTERING MEASUREM
ENT FACILITY        *":CHR$(128)
11480   PRINT "         ":CHR$(129):"*
*":CHR$(128)
11490   PRINT "         ":CHR$(129):"*******************************************
*******************":CHR$(128)
11500 SUBEND
11510 !
11520 !
11530 SUB Draw_pl(Ymax,Ymin,Xmin,Xmax,Dm,Num_traces)
11540 ! Written by Dana J. Bergey, May 1989
11550   Num_traces=0
11560   CALL Clear_crt
11570   Num_div=8
11580   IF Xmin=6 THEN Num_div=6
11590   IF Dm=-1 THEN Num_div=10
11600   PRINT ""
11610   PRINT ""
11620   PRINT ""
11630   PRINT "              Ensure that paper and two pens are in the plotter at th
e time."
11640   PRINT ""
11650   PRINT "                              Press ":CHR$(129):"CONTINUE":CHR$(129)
:" when [illegible]"
11660   [illegible]
```

```
11670   CALL Clear_crt
11680   PRINT "                    Please ";CHR$(130);"Wait";CHR$(128);" while t
he grid is plotted."
11690   PRINTER IS 705
11700   ES=CHR$(3)
11710   PRINT "IN;SP1;IP 1500,2000,9500,7500;"
11720   PRINT "SC0,801,0,100;"
11730   PRINT "PU 0,0 PD,801,0,801,100,0,100,0,0 PU;"
11740   PRINT "SI .2,.3;TL 3,0;"
11750   FOR X=0 TO 801 STEP 801/Num_div
11760     PRINT "PA",X,"0,XT;"
11770   NEXT X
11780   PRINT "TL 1.5,0"
11790   FOR X=0 TO 801 STEP 801/(Num_div*10)
11800     PRINT "PA",X,"0,XT"
11810   NEXT X
11820   PRINT "TL 0,3;"
11830   FOR X=0 TO 801 STEP 801/Num_div
11840     PRINT "PA",X,"100,XT;"
11850   NEXT X
11860   PRINT "TL 0,1.5"
11870   FOR X=0 TO 801 STEP 801/(Num_div*10)
11880     PRINT "PA",X,"100,XT"
11890   NEXT X
11900   FOR X=0 TO 1 STEP 1/Num_div
11910     P=801*X
11920     PRINT "PA",P,"0"
11930     V=Xmin+(Xmax-Xmin)*X
11940     V=PROUND(V,-2)
11950     PRINT "CP -1.5,-1;LB";V;ES
11960   NEXT X
11970   IF Dm=1 THEN PRINT "PA",801/2,"0;CP -8,-2.5; LBFREQUENCY (GHz)";ES
11980   IF Dm=-1 THEN PRINT "PA",801/2,"0;CP -5,-2.5; LBTIME (ns)";ES
11990   PRINT "SC0,1",Ymin,Ymax;"TL 3,0"
12000   Range=Ymax-Ymin
12010   FOR Y=Ymin+10 TO Ymax-10 STEP 10
12020     PRINT "PA0",Y,"YT"
12030   NEXT Y
12040   PRINT "TL 1.5,0"
12050   IF Range>49 THEN Little_tick=2.5
12060   IF Range<51 THEN Little_tick=2
12070   IF Range<31 THEN Little_tick=1
12080   FOR Y=Ymin+Little_tick TO Ymax-Little_tick STEP Little_tick
12090     PRINT "PA 0",Y,"YT"
12100   NEXT Y
12110   PRINT "TL 0,3"
12120   FOR Y=Ymin+10 TO Ymax-10 STEP 10
12130     PRINT "PA 1",Y,"YT"
12140   NEXT Y
12150   PRINT "TL 0,1.5"
12160   FOR Y=Ymin+Little_tick TO Ymax-Little_tick STEP Little_tick
12170     PRINT "PA 1",Y,"YT"
12180   NEXT Y
12190   [illegible]
12200   FOR Y=Ymin TO Ymax STEP 10
12210     PRINT "PA 0",Y;
12220     Ynum=Y
12230     Ynum=PROUND(Ynum,-2)
12240     IF Ynum<-99.99 THEN Offset=6
12250     IF Ynum>-100 AND Ynum<-9.99 THEN Offset=5
12260     IF Ynum>-10 AND Ynum<-.99 THEN Offset=4
```

```
12270       IF Ynum>-1 AND Ynum<0 THEN Offset=3
12280       IF Ynum=0 THEN Offset=0
12290       IF Ynum>0 AND Ynum<1 THEN Offset=2
12300       IF Ynum>.99 AND Ynum<10 THEN Offset=3
12310       IF Ynum>9.99 AND Ynum<100 THEN Offset=4
12320       IF Ynum>99.99 THEN Offset=5
12330       PRINT "CP",(-2.5)-Offset,"-.25;LB";Ynum;E$
12340     NEXT Y
12341     IF Dm=1 THEN
12342        PRINT "PA0",Ymin+Range/2;"DI0,1;CP -5,5"
12343        PRINT "LBRCS (dBsm)";E$
12344     ELSE
12350        PRINT "PA0",Ymin+Range/3;"DI0,1;CP -5,5"
12360        PRINT "LBIMPULSE RESPONSE (dBsm)";E$
12361     END IF
12370     PRINT "DI1,0"
12380     PRINT "PU;PA0",Ymin,";SI .15,.225;CP-5,-5;"
12390     PRINT "LBFile Name      Bandwidth      Polarity     Soft gate      Gate Cent
er";E$
12400     PRINT "LB       Gate Width      Date";E$
12410     PRINT "SP0"
12420     PRINTER IS CRT
12430  SUBEND
12440  !
12450  !
12460  SUB Draw_data(Plot_dt(*),Ymax,Ymin,File_name$,Bandwidth$,Polarity,Pre_gate
$,Gate_cent,Gate_span,Date$,Num_traces,Lin_typ)
12470  !  Written by Dana J. Bergey, May 1989
12480     PRINTER IS 705
12490     PRINT "SC0,801",Ymin,Ymax
12500     PRINT "SP2;"
12510       IF Plot_dt(1)<Ymin THEN Plot_dt(1)=Ymin
12520       IF Plot_dt(1)>Ymax THEN Plot_dt(1)=Ymax
12530     PRINT "PU0",Plot_dt(1);
12540     PRINT "LT2";Lin_typ;";"
12550     IF Lin_typ=0 THEN PRINT "LT;"
12560     FOR I=1 TO 801
12570       IF Plot_dt(I)<Ymin THEN Plot_dt(I)=Ymin
12580       IF Plot_dt(I)>Ymax THEN Plot_dt(I)=Ymax
12590       PRINT "PD",I,Plot_dt(I)
12600     NEXT I
12610     Num_traces=Num_traces+1
12620     PRINT "PU;PA0",Ymin,";SI .15,.225;CP-5,-5;"
12630     E$=CHR$(3)
12640     IF Polarity=0 THEN
12550       Pol$="HORIZONTAL"
12660     ELSE
12670       Pol$="VERTICAL"
12680     END IF
12690     FOR I=0 TO Num_traces
12700       PRINT "CP;CP-5,0;"
12710     NEXT I
12720     PRINT "LB";File_name$;E$
12730     PRINT "CP;CP11,0;"
12740     PRINT "LB";Bandwidth$;E$
12750     PRINT "CP;CP22,0;"
12760     PRINT "LB";Pol$;E$
12770     PRINT "CP;CP35,0;"
12780     PRINT "LB";Pre_gate$;E$
12790     IF Gate_span=0 THEN GOTO No_gate
12800     PRINT "CP;CP49,0;"
```

```
12810   PRINT "LB";Gate_cent;ES
12820   PRINT "CP;CP67,1;"
12830   PRINT "LB";Gate_span;ES
12840 No_gate:  PRINT "CP;CP78,1;"
12850   PRINT "LB";Date$;ES
12860 Bottom:PRINT "SI .2,.3;PU0",Ymin,"SP ;"
12870   PRINTER IS CRT
12880 SUBEND
12890 !
12900 !
12910 SUB Clr_scr
12920   OUTPUT KBD:" K";
12930 SUBEND
12940 !
12950 !
12960 SUB Pat_procplot
12970 !  Written by Dana J. Bergey, May 1989
12980 OPTION BASE 1
12990 DIM Ptrace_data(360),View(365)
13000 Input:CALL Pat_input(Ptrace_data(*),Fr,Date$,File_name2$,Pol,Pre_gate$)
13010 View:CALL View_crt(Ptrace_data(*),File_name2$,Retrn,Coord)
13020 IF Retrn=2 THEN SUBEXIT
13030 IF Retrn=1 THEN GOTO Input
13040 Pmenu:ON KEY 0 GOTO Idle
13050 ON KEY 1 LABEL "LINE TYPE" GOTO Lin_typ
13060 ON KEY 2 GOTO Idle
13070 ON KEY 3 GOTO Idle
13080 ON KEY 4 GOTO Idle
13090 ON KEY 5 LABEL "PLOT GRID" GOTO Pgrid
13100 ON KEY 6 GOTO Idle
13110 ON KEY 7 LABEL "PLOT DATA" GOTO Pdata
13120 ON KEY 8 GOTO Idle
13130 ON KEY 9 LABEL "EXIT" GOTO Pexit
13140 Idle:DISP "ENTER APPROPRIATE SOFT KEY"
13150 GOTO Idle
13160 Lin_typ:CALL Clr_scr
13170 ON KEY 0 LABEL "0" GOTO Zero
13180 ON KEY 1 LABEL "1" GOTO One
13190 ON KEY 2 LABEL "2" GOTO Two
13200 ON KEY 3 LABEL "3" GOTO Three
13210 ON KEY 4 LABEL "4" GOTO Four
13220 ON KEY 5 LABEL "5" GOTO Five
13230 ON KEY 6 LABEL "6" GOTO Six
13240 ON KEY 7 GOTO Lidle
13250 ON KEY 8 GOTO Lidle
13260 ON KEY 9 GOTO Lidle
13270 Lidle:DISP "SELECT LINE TYPE"
13280 GOTO Lidle
13290 Zero:Lin_typ=0
13300 GOTO Pmenu
13310 One:Lin_typ=1
13320 GOTO Pmenu
13330 Two:Lin_typ=2
13340 GOTO Pmenu
13350 Three:Lin_typ=3
13360 GOTO Pmenu
13370 Four:Lin_typ=4
13380 GOTO Pmenu
13390 Five:Lin_typ=5
13400 GOTO Pmenu
13410 Six:Lin_typ=6
```

```
13120 GOTO Pmenu
13430 Pgrid:    CALL Clr_scr
13440 CALL Pscale_cn(Ymax,Ymin,Ptrace_data(*))
13450 CALL Clr_scr
13460 IF Coord=0 THEN CALL Pdraw_pl(Ymax,Ymin,Num_traces)
13470 IF Coord=1 THEN CALL Poldraw_pl(Ymax,Ymin,Num_traces)
13480 GOTO Pmenu
13490 Pdata: CALL Clr_scr
13500 IF Coord=0 THEN CALL Pdraw_data(Ptrace_data(*),Ymax,Ymin,File_name2$,Fr,Po
l,Pre_gate$,Date$,Num_traces,Lin_typ)
13510 IF Coord=1 THEN CALL Poldraw_data(Ptrace_data(*),Ymax,Ymin,File_name2$,Fr,
Pol,Pre_gate$,Date$,Num_traces,Lin_typ)
13520 GOTO Pmenu
13530 Pexit:  CALL Clr_scr
13540 GRAPHICS OFF
13550 GOTO View
13560 SUBEND
13570 !
13580 !
13590 SUB Pat_input(Ptrace_data(*),Fr,Date$,File_name2$,Pol,Pre_gate$)
13600 !  Written by Dana J. Bergey, May 1989
13610 OPTION BASE 1
13620   DIM View(365)
13630   CALL Clr_scr
13640 Start:PRINT ""
13650   PRINT ""
13660   PRINT "           Insert disc containing data file into right hand disk d
rive."
13670   PRINT ""
13680   PRINT "                         Press ";CHR$(131);"CONTINUE";CHR$(128);
" when ready."
13690   PAUSE
13700   ON ERROR GOTO Err2
13710   CALL Clr_scr
13720   INPUT "Do you wish to see listing of disk (Y or N)?  Default is NO.",L1i
st$
13730   IF Llist$="Y" THEN
13740     CAT
13750     ON KBD GOTO Again
13760     DISP CHR$(131);"Press space bar when ready.";CHR$(128)
13770 Lloop:GOTO Lloop
13780   ELSE
13790     GOTO Again
13800   END IF
13810 Again:CALL Clr_scr
13820   OFF KBD
13830   OFF ERROR
13840 Name:INPUT "Enter the file name of the stored file.",File_name2$
13850   ON ERROR GOTO Err1
13860   GOTO Inbound
13870 Err1:PRINT ERRM$
13880   GOTO Name
13890 Inbound:ASSIGN @File2 TO File_name2$
13900   ENTER @File2;View(*)
13910   ASSIGN @File2 TO *
13920   FOR I=1 TO 360
13930   Ptrace_data(I)=View(I
13940   NEXT I
13950   Fr=View(361)
13960   Pol=View(362)
13970   [illegible]_File2$=LWC$(File_name2$)
```

```
13980    ASSIGN @Dte_file2 TO Dte_file2$
13990    ENTER @Dte_file2,1;Date$
14000    ENTER @Dte_file2,2;Pre_gate$
14010    ASSIGN @Dte_file2 TO *
14020    SUBEXIT
14030 Err2:CALL Clr_scr
14040    DISP ERRM$
14050    BEEP
14060    OFF ERROR
14070    GOTO Start
14080 SUBEND
14090    !
14100    !
14110 SUB Pscale_cn(Ymax,Ymin,Ptrace_data(*))
14120 !  Written by Dana J. Bergey, May 1989
14130 GRAPHICS OFF
14140    Ymin=Ptrace_data(1)                  !    INITIALIZE
14150    Ymax=Ymin
14160      FOR J=1 TO 360
14170        IF Ptrace_data(J)<Ymin THEN Ymin=Ptrace_data(J)
14180        IF Ptrace_data(J)>Ymax THEN Ymax=Ptrace_data(J)
14190      NEXT J
14200      CALL Clr_scr
14210     PRINT "         *
    *"
14220     PRINT "         *                         SCALING CHOICES
    *"
14230     PRINT "         *
    *"
14240     PRINT "         ***********************************************************
********"
14250     PRINT ""
14260     PRINT "         The maximum value of the current data is ";Ymax;" (dBsm)."
14270     PRINT "         The minimum value of the current data is ";Ymin;" (dBsm)."
14280     PRINT ""
14290     PRINT "         ";CHR$(129);"AUTO SCALE";CHR$(128);".........Computer gen
erates scale."
14300     PRINT ""
14310     PRINT "         ";CHR$(129);"USER";CHR$(128);"...........    ..User defines
 scale."
14320     PRINT ""
14330     ON KEY 5 LABEL "    AUTO SCALE" GOTO Auto
14340     ON KEY 7 LABEL "      USER" GOTO User
14350     ON KEY 9 GOTO Idle
14360     ON KEY 0 GOTO Idle
14370     ON KEY 1 GOTO Idle
14380     ON KEY 2 GOTO Idle
14390     ON KEY 3 GOTO Idle
14400     ON KEY 4 GOTO Idle
14410     ON KEY 6 GOTO Idle
14420     ON KEY 8 GOTO Idle
14430 Idle:DISP "Enter appropriate soft key."
14440     GOTO Idle
14450 User:CALL Clear_crt
14460     PRINT "         *
    *"
14470     PRINT "         *                         USER DEFINED SCALE
    *"
14480     PRINT "         *
    *"
14490     PRINT "         ***********************************************************
```

```
*******"
14500    PRINT ""
14510    PRINT
14520    INPUT "Enter the maximum value of RCS scale desired.",Ymax
14530    INPUT "Enter the minimum value of RCS scale desired.",Ymin
14540    Range=Ymax-Ymin
14550    IF Range>0 THEN GOTO Good_rge
14560    BEEP
14570    IF Range=0 THEN PRINT "                    You have entered the same value fo
r Ymin and Ymax."
14580    IF Range<0 THEN PRINT "                         Your Ymin is greater than y
our Ymax."
14590    PRINT ""
14600    PRINT "                         Try again!"
14610    GOTO 14520
14620 Good_rge:CALL Clear_crt
14630    OFF KEY
14640    SUBEXIT
14650 Auto:CALL Clear_crt
14660    Ymax=Ymax+10
14670    Ymax=PROUND(Ymax,1)
14680    Ymin=Ymin-10
14690    Ymin=PROUND(Ymin,1)
14700    OFF KEY
14710 SUBEND
14720 !
14730 !
14740 SUB Pdraw_pl(Ymax,Ymin,Num_traces)
14750 !  Written by Dana J. Bergey, May 1989
14760    Num_traces=0
14770    CALL Clr_scr
14780    PRINT ""
14790    PRINT ""
14800    PRINT ""
14810    PRINT "          Ensure that paper and two pens are in the plotter at thi
s time."
14820    PRINT ""
14830    PRINT "                         Press ";CHR$(129);"CONTINUE";CHR$(128)
;" when ready."
14840    PAUSE
14850    CALL Clr_scr
14860    GRAPHICS ON
14870    PRINTER IS 705
14880    E$=CHR$(3)
14890    PRINT "IN;SP1;IP 1500.2000.9500.7500;"
14900    PRINT "SC0.360.0.100;"
14910    PRINT "PU 0.0 PD 360.0.360.100.0.100.0.0 PU;"
14920    PRINT "SI .14.,3;TL 3.0;"
14930    FOR X=45 TO 315 STEP 45
14940      PRINT "PA",X,",0.XT;"
14950    NEXT X
14960    PRINT "TL 1.5.0"
14970    FOR X=5 TO 355 STEP 5
14980      PRINT "PA",X,"0.XT"
14990    NEXT X
15000    PRINT "TL 3.0;"
15010    FOR X=45 TO 315 STEP 45
15020      PRINT "PA",X,"100.XT;"
15030    NEXT X
15040    PRINT "TL 1.5"
15050    FOR X=5 TO 355 STEP 5
```

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15060     PRINT "PA",X,"100,XT"
15070   NEXT X
15080   FOR X=0 TO 360 STEP 45
15090     PRINT "PA",X,"0"
15100     IF X<10 THEN PRINT "CP -1.5,-1:LB";X;ES
15110     IF X>9 AND X<100 THEN PRINT "CP -2,-1:LB";X;ES
15120     IF X>99 THEN PRINT "CP -2.5,-1:LB";X;ES
15130   NEXT X
15140   PRINT "PA 180,0:CP -11,-2.5: LBASPECT ANGLE (DEGREES)";ES
15150   PRINT "SC0,360",Ymin,Ymax;"TL 3,0"
15160   Range=Ymax-Ymin
15170   FOR Y=Ymin+10 TO Ymax-10 STEP 10
15180     PRINT "PA0",Y,"YT"
15190   NEXT Y
15200   PRINT "TL 1.5,0"
15210   IF Range>49 THEN Little_tick=2.5
15220   IF Range<51 THEN Little_tick=2
15230   IF Range<31 THEN Little_tick=1
15240   FOR Y=Ymin+Little_tick TO Ymax-Little_tick STEP Little_tick
15250     PRINT "PA 0",Y,"YT"
15260   NEXT Y
15270   PRINT "TL 0,3"
15280   FOR Y=Ymin+10 TO Ymax-10 STEP 10
15290     PRINT "PA 360 ",Y,"YT"
15300   NEXT Y
15310   PRINT "TL 0,1.5"
15320   FOR Y=Ymin+Little_tick TO Ymax-Little_tick STEP Little_tick
15330     PRINT "PA 360",Y,"YT"
15340   NEXT Y
15350   PRINT "TL 3,0"
15360   FOR Y=Ymin TO Ymax STEP 10
15370     PRINT "PA 0",Y;
15380     Ynum=Y
15390     Ynum=PROUND(Ynum,-2)
15400     IF Ynum<-99.99 THEN Offset=6
15410     IF Ynum>-100 AND Ynum<-9.99 THEN Offset=5
15420     IF Ynum>-10 AND Ynum<-.99 THEN Offset=4
15430     IF Ynum>-1 AND Ynum<0 THEN Offset=3
15440     IF Ynum=0 THEN Offset=0
15450     IF Ynum>0 AND Ynum<1 THEN Offset=2
15460     IF Ynum>.99 AND Ynum<10 THEN Offset=3
15470     IF Ynum>9.99 AND Ynum<100 THEN Offset=4
15480     IF Ynum>99.99 THEN Offset=5
15490     PRINT "CP",(-2.5)-Offset,"-.25:LB";Ynum;ES
15500   NEXT Y
15510   PRINT "PA0",Ymin+Range/2;"DI0,1;CP -5,5"
15520   PRINT "LBRCS (dBsm)";ES
15530   PRINT "DI1,0"
15540   PRINT "PU,PA0",Ymin,"DI .15,.225:CP5,-5:"
15550   PRINT "LBFile Name          Frequency          Polarization          Soft gate
   Date";ES
15560   PRINT "PG0"
15570   PRINTER IS CRT
15580   SUBEND
15590   !
15600   !
15610 SUB Pdraw_data(Ptrace_data(*),Ymax,Ymin,File_name2$,Fr,Pol,Pre_gate$,Date$
,Num_traces,Lir_typ)
15620 ! WRITTEN BY Dana J. Sergey, May 1989
15630 ! 
15640   PRINT "SC 0,360,",Ymin,Ymax
```

```
15650    PRINT "SP2;"
15660    PRINT "PU0",Ptrace_data(1);
15670    PRINT "LT2,";Lin_typ;";"
15680    IF Lin_typ=0 THEN PRINT "LT;"
15690    FOR I=1 TO 360
15700      IF Ptrace_data(I)<Ymin THEN Ptrace_data(I)=Ymin
15710      IF Ptrace_data(I)>Ymax THEN Ptrace_data(I)=Ymax
15720      PRINT "PD",I,Ptrace_data(I)
15730    NEXT I
15740    Num_traces=Num_traces+1
15750    PRINT "PU;PA0",Ymin,";SI .15,.225;CP5,-5;"
15760    E$=CHR$(3)
15770    IF Pol=1 THEN
15780      Pol$="VERTICAL"
15790    ELSE
15800      Pol$="HORIZONTAL"
15810    END IF
15820    FOR I=0 TO Num_traces
15830      PRINT "CP0,-1;"
15840    NEXT I
15850    PRINT "LB";File_name2$;E$
15860    PRINT "CP;CP20,1;"
15870    PRINT "LB";Fr;"GHz";E$
15880    PRINT "CP;CP38,1;"
15890    PRINT "LB";Pol$;E$
15900    PRINT "CP;CP59,1;"
15910    PRINT "LB";Pre_gate$;E$
15920    PRINT "CP;CP69,1;"
15930    PRINT "LB";Date$;E$
15940 Bottom:PRINT "SI .2,.3;PU0",Ymin,"SP ;"
15950    PRINTER IS CRT
15960 SUBEND
15970 !
15980 !
15990 SUB View_crt(View(*),File_name2$,Retrn,Coord)
16000 !  Written by Dana J. Bergey, May 1989
16010 Start:  CALL Clr_scr
16020    GINIT
16030    PLOTTER IS 3,"INTERNAL"
16040    Ymin=View(1)
16050    Ymax=Ymin
16060    FOR I=1 TO 359
16070      IF View(I)<Ymin THEN Ymin=View(I)
16080      IF View(I)>Ymax THEN Ymax=View(I)
16090    NEXT I
16100    Ymax=Ymax+10
16110    Ymax=PROUND(Ymax,1)
16120    Ymin=Ymin-10
16130    Ymin=PROUND(Ymin,1)
16140    Range=Ymax-Ymin
16150    GRAPHICS ON
16160    MOVE 0,95
16170    CSIZE 3
16180    LABEL File_name2$
16190    CSIZE 6
16200    LORG 6
16210    FOR I=-.3 TO .3 STEP .1
16220      MOVE 70+I,100
16230      LABEL "LOW OBSERVABLES"
16240    NEXT I
16250    LORG 1
```

```
6260    CSIZE 4
6270    MOVE 0,82
6280    Label$="500"
6290    FOR I=1 TO 3
6300      LABEL Label$(I,I)
6310    NEXT I
6320    MOVE 55,15
6330    LABEL "ASPECT ANGLE"
6340    VIEWPORT 15,125,30,95
6350    FRAME
6360    WINDOW 0,360,Ymin,Ymax
6370    AXES 5,2,0,Ymin,9,5,2
6380    CSIZE 3
6390    LORG 6
6400    CLIP OFF
6410    FOR I=0 TO 360 STEP 45
6420      MOVE I,Ymin-1
6430      LABEL I
6440    NEXT I
6450    LORG 8
6460    FOR I=Ymin TO Ymax STEP 10
6470      MOVE -1,I
6480      LABEL I
6490    NEXT I
6500    FOR I=0 TO 359
6510      PLOT I,View(I+1)
6520    NEXT I
6530    ON KEY 4 LABEL "DUMP TO PRNTR" GOTO Ddump
6540    ON KEY 0 LABEL "PLOT RECT." GOTO Plotr
6550    ON KEY 1 GOTO Idle
6560    ON KEY 2 LABEL "PLOT POLAR" GOTO Plotp
6570    ON KEY 3 GOTO Idle
6580    ON KEY 5 LABEL "NEW DATA" GOTO New_data
6590    ON KEY 6 GOTO Idle
6600    ON KEY 7 LABEL "SHIFT DATA" GOTO Shift
6610    ON KEY 8 GOTO Idle
6620    ON KEY 9 LABEL "EXIT" GOTO Exit
6630 Idle:DISP "PRESS APPROPRIATE SOFT KEY"
6640    GOTO Idle
6650 Ddump:PRINTER IS 701
6660    OUTPUT KBD:" N":
6670    PRINTER IS CRT
6680    GOTO Idle
6690 Shift:  CALL Clr_scr
6700    DIM View2(361)
6710    INPUT "How many degrees should the data be shifted ?  (- for shift left)
",Dshift
6720    ON ERROR GOTO 16710
6730    IF Dshift<-360 OR Dshift>360 THEN GOTO 16710
6740    IF Dshift>0 THEN
6750      Dshift=360-Dshift
6760    ELSE
6770      Dshift=-1*Dshift
6780    END IF
6790    FOR I=1 TO 360-Dshift
6800    View2(I)=View(I+Dshift)
6810    NEXT I
6820    FOR I2=1 TO Dshift
6830    View2(360-Dshift+I2)=View(I2)
6840    NEXT I2
6850    FOR I3=1 TO 360
```

```
16860     View(I3)=View2(I3)
16870     NEXT I3
16880     GOTO Start
16890 Plotr:CALL Clr_scr
16900     Retrn=0
16910     Coord=0
16920     SUBEXIT
16930 Plotp:  CALL Clr_scr
16940     Retrn=0
16950     Coord=1
16960     SUBEXIT
16970 New_data: GRAPHICS OFF
16980     Retrn=1
16990     CALL Clr_scr
17000     SUBEXIT
17010 Exit:   GRAPHICS OFF
17020     Retrn=2
17030     CALL Clr_scr
17040     SUBEND
17050 !
17060 !
17070 SUB Poldraw_plt(Ymax,Ymin,Num_traces)
17080 !  written by Dana J. Bergey, May 1989
17090     Num_traces=0
17100     CALL Clr_scr
17110     PRINT ""
17120     PRINT ""
17130     PRINT ""
17140     PRINT "            Ensure that paper and two pens are in the plotter at thi
s time."
17150     PRINT ""
17160     PRINT "                              Press ";CHR$(129);"CONTINUE";CHR$(128)
;" when ready."
17170     PAUSE
17180     CALL Clr_scr
17190     PRINTER IS 705
17200     E$=CHR$(3)
17210     PRINT "IN;SP1;IP 1000,900,9000,8900"
17220     PRINT "SC",Ymin,Ymax,Ymin,Ymax
17230     Cntr=Ymax-(Ymax-Ymin)/2
17240     Numcirc=(Ymax-Ymin)/10
17250     Radmax=(Ymax-Ymin)/2
17260     FOR I=1 TO Numcirc
17270     FOR T=0 TO 2*PI STEP PI/50
17280     X=Cntr+(COS(T)*Radmax/Numcirc*I)*.81
17290     Y=Cntr+SIN(T)*Radmax/Numcirc*I
17300     PRINT USING 17310;"PA",X,Y,"PD;"
17310     IMAGE 2A,2(MDD.DDDD),3A
17320     NEXT T
17330     PRINT "PU"
17340     NEXT I
17350     PRINT "PU;LT2,1"
17360     FOR T=0 TO 2*PI-PI/18 STEP PI/18
17370     Strtx=Cntr+Radmax*COS(T)*.81
17380     Strty=Cntr+Radmax*SIN(T)
17390     PRINT "PU;PA",Strtx,Strty
17400     Endx=Cntr+Radmax/Numcirc*COS(T)*.81
17410     Endy=Cntr+Radmax/Numcirc*SIN(T)
17420     PRINT "PD;PA",Endx,Endy
17430     NEXT T
17440     PRINT "LT;DI1,0"
```

```
17450   Pos1=Cntr-Radmax/12
17460   PRINT "PU;PA",Pos1,Cntr
17470   PRINT "LB";Ymin;E$
17480   PRINT "LBdBsm";E$
17490   Pos2=Ymax-Radmax/6
17500   PRINT "PU;PA",Pos2,Cntr
17510   PRINT "LB";Ymax;E$
17520   PRINT "LBdBsm, 0 degrees";E$
17530   D90x=Cntr-(Ymax-Ymin)/20
17540   D90y=Cntr+Radmax
17550   !  PRINT "PU;PA",D90x,D90y
17560   !  PRINT "LB90 degrees";E$
17570   D180x=Cntr-Radmax*7/6
17580   D180y=Cntr
17590   PRINT "PU;PA",D180x,D180y
17600   PRINT "LB180 degrees";E$
17610   Wrdsx=Cntr-Radmax*.8
17620   Wrdsy=Cntr-Radmax*.8
17630   PRINT "PU;PA",Wrdsx,Wrdsy,";SI .15,.225;CP0,-5;"
17640   PRINT "LBFile Name        Frequency        Polarization      Soft gate
  Date";E$
17650   PRINT "SP0"
17660   PRINTER IS CRT
17670 SUBEND
17680 !
17690 !
17700 SUB Poldraw_data(Ptrace_data(*),Ymax,Ymin,File_name$,Fr,Pol,Pre_gate$,Date
$,Num_traces,Lin_typ)
17710 !  Written by Dana J. Bergey, May 1989
17720   PRINTER IS 705
17730   PRINT "IP 1000,900,9000,8900;SC",Ymin,Ymax,Ymin,Ymax
17740   PRINT "SP2;"
17750   Numcirc=(Ymax-Ymin)/10
17760   Radmax=(Ymax-Ymin)/2
17770   Extra=Radmax/Numcirc
17780   Cntr=Ymax-(Ymax-Ymin)/2
17790   Xp=Cntr+.5*(Ptrace_data(1)-Ymin)*.81
17800   PRINT "PU",Xp,Cntr
17810   PRINT "LT2";Lin_typ;";"
17820   IF Lin_typ=0 THEN PRINT "LT;"
17830   FOR I=1 TO 360
17840   Theta=I/180*3.14159
17850   X=(Ptrace_data(I)-Ymin)*COS(Theta)*.81
17860   Xp=Cntr+X/2
17870   Y=(Ptrace_data(I)-Ymin)*SIN(Theta)
17880   Yp=Cntr+Y/2
17890     PRINT "PD",Xp,Yp
17900   NEXT I
17910   Num_traces=Num_traces+1
17920   Xp=Cntr+.5*(Ptrace_data(1)-Ymin)*.81
17930   PRINT "PD",Xp,Cntr
17940   Wrdsx=Cntr-Radmax*.8
17950   Wrdsy=Cntr-Radmax*.8
17960   PRINT "PU;PA",Wrdsx,Wrdsy,";SI .15,.225;CP0,-4;"
17970   E$=CHR$(3)
17980   IF Pol=1 THEN
17990     Pol$="HORIZONTAL"
18000   ELSE
18010     Pol$="VERTICAL"
18020   END IF
18030   FOR I=0 TO Num_traces
```

```
18040       PRINT "CP0,-1;"
18050     NEXT I
18060     PRINT "LB";File_name$;E$
18070     PRINT "CP;CP16,1;"
18080     PRINT "LB";Fr;" GHz";E$
18090     PRINT "CP;CP33,1;"
18100     PRINT "LB";Pol$;E$
18110     PRINT "CP;CP52,1;"
18120     PRINT "LB";Pre_gate$;E$
18130     PRINT "CP;CP54,1;"
18140     PRINT "LB";Date$;E$
18150     Out=Cntr-Radmax
18160     PRINT "PU";Cntr,Out,";SP0;"
18170     PRINTER IS CRT
18180 SUBEND
18190 !
```

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Vita

Captain Scott A. Owens [redacted] four years prior to receiving his Bachelor of Science degree in Electrical Engineering from Clarkson University in May of 1985. Captain Owens received his commission in the USAF as a distinguished graduate from the University's ROTC program and entered active duty in September 1985. His first assignment was to the Avionics Laboratory of the Air Force Wright Aeronautical Laboratories (AFWAL) at Wright Patterson AFB, Ohio. Captain Owens worked in offensive and defensive avionics in the Mission Avionics Division until entering the School of Engineering, Air Force Institute of Technology, in May 1988.

[redacted]

The purpose of this study was twofold. The first objecive was to complete the develpment of AFIT's Far-Field Radar Range with a fully automated measurement process. The second objective was to use the facility to investigate the scattering of metallic versus transparent aircraft canopies relative to the scattering of the total aircraft. The approach for the investigation was: first, to measure scale model aircraft to determine the effect of the RCS of the canopy/cockpit area on the RCS of the total aircraft, and second, to design and measure a test body which would isolate the canopy/cockpit area from the rest of the aircraft.

The result of the work on the first task is a software package called AFIT RCS Measurement Software (ARMS). The successful performance of the far-field range was validated by very favorable comparisons with the Wright Research and Development Center's anechoic chamber. The scale model measurements suggest at most a 5 dB difference between the scattering from the two extreme cases. The test body, however, clearly demonstrated differences up to 20 dB at certain frequencies.

This study documents the upper and lower bounds of the subject measurements in an indoor measurement range. The Air Force has expressed interest in steering the investigation to examine materials and/or canopy construction.

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